Water Quality Special Study Report

U.S. Army Corps of Engineers
Omaha District

Water Quality Conditions Monitored at the Corps' Oahe Project in South Dakota during the 3-Year Period 2005 through 2007

Aerial Photo of Oahe Dam, Tailwaters and Reservoir

Report Number: CENWO-ED-HA/WQSS/Oahe/2008

February 2008

Report Documentation Page	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE **FEB 2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE **Water Quality Conditions Monitored at the Corps' Oahe Project in South Dakota during the 3-Year Period 2005 through 2007**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Army Corps of Engineers,Omaha District,1616 Capital Avenue Ste 9000,Omaha,NE,68102**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a REPORT **unclassified**	b ABSTRACT **unclassified**	c THIS PAGE **unclassified**	**Same as Report (SAR)**	**145**	

(Page left intentionally blank)

Water Quality Special Report

Water Quality Conditions Monitored at the Corps' Oahe Project in South Dakota during the 3-Year Period 2005 through 2007

(Report Number: CENWO-ED-HA/WQSS/Oahe/2008)

Prepared by:

Water Quality Unit
Water Control and Water Quality Section
Hydrologic Engineering Branch
Engineering Division
Omaha District
U.S. Army Corps of Engineers

February 2008

For Information Regarding This Document Please Contact:

U.S. Army Corps of Engineers, Omaha District
Attention: CENWO-ED-HA
106 South 15th Street
Omaha, Nebraska 68102-1619

TABLE OF CONTENTS

List of Tables

Page

List of Figures

List of Plates

Page

EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (Corps) Oahe Project consists of Oahe Dam and Oahe Reservoir. Oahe Dam is located on the Missouri River at river mile (RM) 1072.3 in central South Dakota, 6 miles northwest of Pierre, South Dakota. The reservoir and dam are authorized for the uses of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Habitat for one endangered species, interior least tern (*Sterna antillarum*), and one threatened species, piping plover (*Charadrius melodus*), occurs in the Missouri River upstream and downstream of the reservoir. Recreation at Oahe Reservoir is of great economic importance to the State of South Dakota, especially with respect to the reservoir's fishery. Oahe Reservoir currently maintains a "two-story" fishery that is comprised of warmwater and coldwater species. The ability of the reservoir to maintain a "two-story" fishery is due to the reservoir's thermal stratification in the summer into a colder bottom region and warmer surface region.

Water quality monitoring was conducted at the Oahe Project by the Omaha District over the 3-year period of 2005 through 2007. The water quality monitoring conducted included: 1) continuing long-term, fixed-station monitoring in the reservoir at a near-dam deepwater location; 2) monthly sampling and continuous monitoring (i.e., hourly) of water quality conditions in the powerhouse of water discharged through Oahe Dam; and 3) intensive water quality surveys in 2005, 2006, and 2007. The results of this monitoring were used to assess the existing water quality conditions of Oahe Reservoir.

Overall, the existing water quality conditions monitored in Oahe Reservoir were good. Water quality conditions in Oahe Reservoir vary along its length, and strong thermal stratification occurs in the deeper area of the reservoir during the summer. Water quality monitoring indicated that the trophic status of the downstream half of the reservoir is mesotrophic; while the upstream half is moderately eutrophic to eutrophic. The phytoplankton community of Oahe Reservoir was dominated by diatoms and only minor "blooms" of cyanobacteria were monitored.

Water discharged through Oahe Dam exhibited good water quality. The temperature of the discharge water is reflective of the mid-depth elevation of its withdrawal from Oahe Reservoir. During drought conditions when reservoir pool levels are low, the invert elevation of the intake for the power tunnels is at or above the elevation of the thermocline during summer thermal stratification of the reservoir. Under these conditions, the temperature of water discharged through Oahe Dam is reflective of the water temperatures near the reservoir surface.

Inflow temperatures of the Missouri River to Oahe Reservoir are generally warmer than the outflow temperatures of Oahe Dam during the period of April through June. Outflow temperatures of the Oahe Dam discharge are generally warmer than the inflow temperatures of the Missouri River during the period of July through March. A maximum temperature difference occurs in the late-fall and early-winter when the Oahe Dam discharge temperature is about 4°C warmer than the Missouri River inflow temperature.

The Omaha District is planning to pursue the application of the Corps' CE-QUAL-W2 (Version 3.2) hydrodynamic and water quality model to Oahe Reservoir. CE-QUAL-W2 is an extremely powerful tool to aid in addressing reservoir water quality management issues. Application of the CE-QUAL-W2 model will allow the Corps to better understand how the operation of the Oahe Project affects the water quality of Oahe Reservoir and the Missouri River below Oahe Dam. It is almost a certainty that water quality issues at the Oahe Project will remain important in the future.

(Page left intentionally blank)

1 INTRODUCTION

1.1 RECENT WATER QUALITY MONITORING AT THE CORPS' OAHE PROJECT

Water quality monitoring conducted by the Omaha District (District) at the Oahe Project over the past 3 years included 1) continuing long-term, fixed-station monitoring in the reservoir at a near-dam deepwater location; 2) monthly sampling and continuous monitoring (i.e., hourly) of water quality conditions in the powerhouse of water discharged through Oahe Dam; and 3) intensive water quality surveys in 2005, 2006, and 2007. The continuing long-term, fixed-station monitoring consisted of monthly (i.e., May through September) field measurements and sample collection. The monitoring in the Oahe powerhouse was on water drawn from the penstocks prior to passing through the dam's turbines. The intensive surveys included monitoring at six additional in-reservoir sites and monitoring of the Missouri and Cheyenne River inflows to the reservoir. This report presents the findings of the water quality monitoring conducted by the District at the Oahe Project during the period 2005 though 2007.

1.2 MISSOURI RIVER MAINSTEM SYSTEM

The Missouri River Mainstem System (Mainstem System) is comprised of six dams and reservoirs constructed by the U.S. Army Corps of Engineers (Corps) on the Missouri River and the free-flowing Missouri River downstream of the project dams. The six reservoirs impounded by the dams contain about 73.3 million acre-feet (MAF) of storage capacity and, at normal pool, an aggregate water surface area of about 1 million acres. The six dams and reservoirs in an upstream to downstream order are: Fort Peck Dam and Reservoir (Montana), Garrison Dam and Reservoir (North Dakota), Oahe Dam (South Dakota) and Oahe Reservoir (North and South Dakota), Big Bend Dam and Reservoir (South Dakota), Fort Randall Dam and Reservoir (South Dakota), and Gavins Point Dam and Reservoir (South Dakota and Nebraska). The water in storage at the all Mainstem System reservoirs at the end of 2007 (i.e., December 2007) was 36.839 MAF, which is 50 percent of the total system storage volume and 70 percent of the 1967-2007 average. Several years of drought conditions in the upper Missouri River Basin have reduced the water stored in the Mainstem System reservoirs to record low levels.

1.2.1 REGULATION OF THE MAINSTEM SYSTEM

The Mainstem System is a hydraulically and electrically integrated system that is regulated to obtain the optimum fulfillment of the multipurpose benefits for which the dams and reservoirs were authorized and constructed. The Congressionally authorized purposes of the Mainstem System are flood control, navigation, hydropower, water supply, water quality, irrigation, recreation, and fish and wildlife (including threatened and endangered species). The Mainstem System is operated under the guidelines described in the Missouri River Mainstem System Master Water Control Manual, (Master Manual) (USACE-RCC, 2004). The Master Manual details regulation for all authorized purposes as well as emergency regulation procedures in accordance with the authorized purposes.

Mainstem System regulation is, in many ways, a repetitive annual cycle that begins in late winter with the onset of snowmelt. The annual melting of mountain and plains snowpacks along with spring and summer rainfall produces the annual runoff into the Mainstem System. In a typical year, mountain snowpack, plains snowpack, and rainfall events, respectively, contribute 50, 25, and 25 percent of the annual runoff to the Mainstem System. After reaching a peak, usually during July, the amount of water stored in the Mainstem System declines until late in the winter when the cycle begins anew. A similar pattern may be found in rates of releases from the Mainstem System, with the higher levels of flow from mid-March to late November, followed by low rates of winter discharge from late November until mid-March, after which the cycle repeats.

To maximize the service to all the authorized purposes, given the physical and authorization limitations of the Mainstem System, the total storage available is divided into four regulation zones that are applied to the individual reservoirs. These four regulation zones are: 1) Exclusive Flood Control Zone, 2) Annual Flood Control and Multiple Use Zone, 3) Carryover Multiple Use Zone, and 4) Permanent Pool Zone.

1.2.1.1 Exclusive Flood Control Zone

Flood control is the only authorized purpose that requires empty space in the reservoirs to achieve the objective. A top zone in each Mainstem System reservoir is reserved for use to meet the flood control requirements. This storage space is used only for detention of extreme or unpredictable flood flows and is evacuated as rapidly as downstream conditions permit, while still serving the overall flood control objective of protecting life and property. The Exclusive Flood Control Zone encompasses 4.7 MAF and represents the upper 6 percent of the total Mainstem System storage volume. This zone, from 73.3 MAF down to 68.7 MAF, is normally empty. The four largest reservoirs, Fort Peck, Garrison, Oahe, and Fort Randall, contain 97 percent of the total storage reserved for the Exclusive Flood Control Zone.

1.2.1.2 Annual Flood Control and Multiple Use Zone

An upper “normal operating zone” is reserved annually for the capture and retention of runoff (normal and flood) and for annual multiple-purpose regulation of this impounded water. The Mainstem System storage capacity in this zone is 11.7 MAF and represents 16 percent of the total system storage volume. This storage zone, which extends from 68.7 MAF down to 57.0 MAF, will normally be evacuated to the base of this zone by March 1 to provide adequate storage capacity for capturing runoff during the next flood season. On an annual basis, water will be impounded in this zone, as required to achieve the Mainstem System flood control purpose, and also be stored in the interest of general water conservation to serve all the other authorized purposes. The evacuation of water from the Annual Flood Control and Multiple Use Zone is scheduled to maximize service to the authorized purposes that depend on water from the system. Scheduling releases from this zone is limited by the flood control objective in that the evacuation must be completed by the beginning of the next flood season. This is normally accomplished as long as the evacuation is possible without contributing to serious downstream flooding. Evacuation is, therefore, accomplished mainly during the summer and fall because Missouri River ice formation and the potential for flooding from higher release rates limit release rates during the December through March period.

1.2.1.3 Carryover Multiple Use Zone

The Carryover Multiple Use Zone is the largest storage zone extending from 57.0 MAF down to 18.0 MAF and represents 53 percent of the total system storage volume. Serving the authorized purposes during an extended drought is an important regulation objective of the Mainstem System. The Carryover Multiple Use Zone provides a storage reserve to support authorized purposes during drought conditions. Providing this storage is the primary reason the upper three reservoirs of the Mainstem System are so large compared to other Federal water resource projects. The Carryover Multiple Use Zone is often referred to as the “bank account” for water in the Mainstem System because of its role in supporting authorized purposes during critical dry periods when the storage in the Annual Flood Control and Multiple Use Zone is exhausted. Only the reservoirs at Fort Peck, Garrison, Oahe, and Fort Randall have this storage as a designated storage zone. The three larger reservoirs (Fort Peck, Garrison, and Oahe) provide water to the Mainstem System during drought periods to provide for authorized purposes. The storage space assigned to this zone in Fort Randall Reservoir serves a different purpose. It is normally evacuated each year during the fall season to provide recapture space for upstream winter power releases. The recapture results in complete refill of Fort Randall Reservoir during the winter months. During drought periods, the three smaller project (Fort Randall, Big Bend, and Gavins Point) reservoir levels are maintained at the same elevation they would be at if runoff conditions were normal.

1.2.1.4 <u>Permanent Pool Zone</u>

The Permanent Pool Zone is the bottom zone that is intended to be permanently filled with water. The zone provides for future sediment storage capacity and maintenance of minimum pool levels for power heads, irrigation diversions, water supply, recreation, water quality, and fish and wildlife. A drawdown into this zone is generally not scheduled except in unusual conditions. The Mainstem System storage capacity in this storage zone is 18.0 MAF and represents 25 percent of the total storage volume. The Permanent Pool Zone extends from 18.0 MAF down to 0 MAF.

1.2.2 WATER CONTROL PLAN FOR THE MAINSTEM SYSTEM

Variations in runoff into the Mainstem System necessitates varied regulation plans to accommodate the multipurpose regulation objectives. The two primary high-risk flood periods are the plains snowmelt and rainfall period extending from late February through April, and the mountain snowmelt and rainfall period extending from May through July. Also, the winter ice-jam flood period extends from mid-December through February. The highest average power generation period extends from mid-April to mid-October, with high peaking loads during the winter heating season (mid-December to mid-February) and the summer air conditioning season (mid-June to mid-August). The power needs during the winter are supplied primarily with Fort Peck and Garrison Dam releases and the peaking capacity of Oahe and Big Bend Dams. During the spring and summer period, releases are normally geared to navigation and flood control requirements, and primary power loads are supplied using the four lower dams. During the fall when power needs diminish, Fort Randall is normally drawn down to permit generation during the winter period when Oahe and Big Bend peaking-power releases refill the reservoir. The normal 8-month navigation season extends from April 1 through November 30, during which time Mainstem System releases are increased to meet downstream target flows in combination with downstream tributary inflows. Winter releases after the close of the navigation season are much lower and vary, depending on the need to conserve or evacuate storage volumes with downstream ice conditions permitting. Releases and pool fluctuations for fish spawning management generally occur from April 1 through June. Two threatened and endangered bird species, piping plover (*Charadrius melodus*) and least tern (*Sterna antillarum*), nest on "sandbar" areas from early May through mid-August. Other factors may vary widely from year to year, such as the amount of water-in-storage and the magnitude and distribution of inflow received during the coming year. All these factors will affect the timing and magnitude of Mainstem System releases. The gain or loss in the water stored at each reservoir must also be considered in scheduling the amount of water transferred between reservoirs to achieve the desired storage levels and to generate power. These items are continually reviewed as they occur and are appraised with respect to the expected range of regulation.

1.3 DESCRIPTION OF THE OAHE PROJECT

Oahe Dam and Reservoir are authorized for the purposes of flood control, recreation, fish and wildlife, hydroelectric power production, water supply, water quality, navigation, and irrigation. Habitat for one endangered species, interior least tern, and one threatened species, piping plover, occurs in the Missouri River upstream and downstream of the reservoir.

1.3.1 OAHE DAM AND POWERPLANT

Oahe Dam is located on the Missouri River at river mile (RM) 1072.3 in central South Dakota, 6 miles northwest of Pierre, South Dakota. Construction of Oahe Dam was initiated in September 1948. Closure of the dam was completed in 1958, and deliberate accumulation of storage was begun in late 1961. Oahe Dam is a compacted earthen embankment flanked by massive shale berms, both upstream and downstream. Outlet works tunnels are located in the right abutment (west end) and power tunnels in the left abutment (east end). The total embankment length, excluding the spillway, is 9,300 feet and the maximum dam height is 245 feet. The concrete spillway is located approximately 1 mile from the dam on the west end. The top elevation of the dam is 1660 ft-msl. Work on the powerplant and associated structures was started in 1958. The first of seven generating units began delivery of power in April 1962, and the last unit began producing power in June 1963. Over the period 1967 through 2007, the seven generating units at Oahe Dam have produced an annual average 2.677 million mega-watt hours (MWh) of electricity, which has a current revenue value of approximately $40 million. The ongoing drought in the interior western United States has curtailed releases and power production at the Missouri River mainstem system projects, including Oahe. Power production at the Oahe Dam generating units averaged an annual 1.325 MWh over the 3-year period 2005 through 2007.

The Oahe Dam outlet works located on the west bank of the river consists of an approach channel, six tunnels with intake and control structures, a stilling basin, and a discharge channel. These facilities can be used to control releases from the reservoir and are capable of discharging 111,000 cfs when the reservoir is filled to the maximum operating pool of 1620 ft-msl. The approach channel leading southerly from the river channel to the tunnel intakes is approximately 2,000 feet long. The upstream portion of the channel next to the river (1,300 feet long) is straight and is made up of a channel on two levels. The lower level channel is at elevation 1425 ft-msl with a 100-foot bottom width. The upper channel (a berm 60 feet wide) parallels the lower level channel on the west at an elevation of 1455 ft-msl. The remaining length of the approach channel curves toward the intake structure. The intake structure consists of six individual intakes to the outlet works tunnels. The six intake structures are staggered in plan and elevation. The No. 1 structure is set furthermost upstream with the lowest invert elevation of 1425 ft-msl. Each succeeding intake is set back approximately 700 feet with the invert elevation raised in 6-foot increments. A 9,000 foot long discharge channel conveys water from the outlet works tunnels back to the river channel below the dam.

The intake superstructures and the drop inlet shafts for the power tunnels are located near the east abutment of Oahe Dam. The intake superstructures consist of seven individual control towers, 145 feet high, located in an excavated area at elevation 1520 ft-msl a short distance upstream from the toe of the dam embankment slope. The seven individual control towers have inverts for water intake set at elevation 1524 ft-msl; 114 ft above the reservoir bottom. The shafts below the intakes are drop inlets connected to the power tunnels which convey water downstream to the powerplant for power production.

1.3.2 OAHE RESERVOIR

The closing of Oahe Dam in 1958, and the deliberate accumulation of storage in 1961, resulted in the formation of Oahe Reservoir. The Permanent Pool storage space in Oahe Reservoir was first filled in 1962 and the Carryover Multiple Use Zone was filled in 1967. Generally, the Carryover Multiple Use Zone remained filled from that time through 2002, except for seasonal drawdowns in the interest of increased winter power generation and the two drought periods to date. The Exclusive Flood Control Zone in Oahe Reservoir was used in 1975, 1984, 1986, 1995, 1996, 1997, and 1999. The maximum of record elevation was experienced on June 25, 1995, at 1618.7 ft-msl, when the Oahe pool occupied 1.7 feet of the 3-foot Exclusive Flood Control Zone. Due to ongoing drought conditions, the reservoir, at the end of December 2007, was at pool elevation 1582.2 ft-msl. This is 25.3 feet below the top of the Carryover Multiple Use Zone (1607.5 ft-msl).

When full, Oahe Reservoir is 231 miles long, covers 312,120 acres, and has 2,250 miles of shoreline. Table 1.1 summarizes how the surface area, volume, mean depth, and retention time of Oahe Reservoir vary with pool elevations. Major inflows to Oahe Reservoir are the Missouri River, Grand River, Moreau River, and Cheyenne River. The reservoir is used as a water supply by the town of Fort Yates, North Dakota; the towns of Bear Creek, Blackfoot, Bridger, Cherry Creek, Dupree, Eagle Butte, Faith, Gettysburg, Green Grass, Iron Lightning, Lantry, LaPlante, Mobridge, Promise, Red Elm, Red Schaffold, Swiftbird, Thunder Butte, Wakpala, and White Horse, South Dakota; and by some individual cabins. Cooling water for the individual units in the Oahe powerplant is drawn from the water going through the units. Oahe Reservoir is an important recreational resource and a major visitor destination in South Dakota.

Table 1.1. Surface area, volume, mean depth, and retention time of Oahe Reservoir at different pool elevations.

Elevation (Feet-msl)	Surface Area (Acres)	Volume (Acre-Feet)	Mean Depth (Feet)*	Retention Time (Years)**
1620	374,135	23,136,960	61.8	1.32
1615	350,960	21,323,520	60.8	1.21
1610	325,965	19,630,460	60.3	1.12
1605	300,030	18,068,750	60.2	1.03
1600	281,010	16,618,390	59.1	0.94
1595	260,715	15,265,460	58.6	0.87
1590	245,190	14,002,600	57.1	0.80
1585	229,085	12,816,650	55.9	0.73
1580	213,150	11,711,030	54.9	0.67
1575	196,915	10,686,750	54.3	0.61
1570	182,933	9,737,896	53.2	0.55
1565	168,523	8,859,708	52.6	0.50
1560	155,510	8,049,792	51.8	0.46
1555	141,688	7,308,917	51.6	0.42
1550	133,628	6,622,830	49.6	0.38
1545	124,869	5,976,361	47.9	0.34
1540	116,560	5,373,030	46.1	0.31

Average Annual Inflow (1967 through 2006) = 18.28 Million Acre-Feet
Average Annual Outflow: (1967 through 2006) = 17.59 Million Acre-Feet
* Mean Depth = Volume ÷ Surface Area.
** Retention Time = Volume ÷ Average Annual Outflow.
Note: Exclusive Flood Control Zone (elev. 1620-1617 ft-msl), Annual Flood Control and Multiple Use Zone (elev. 1617-1607.5 ft-msl), Carryover Multiple Use Zone (elev. 1607.5-1540 ft-msl), and Permanent Pool Zone (elev. 1540-1415 ft-msl).

1.3.3 MISSOURI RIVER DOWNSTREAM OF OAHE DAM

The Missouri River from Oahe Dam flows in a southerly direction for about 7 miles in an unchannelized river before entering the headwaters of Big Bend Reservoir. This reach is relatively straight and confined to one channel. No large tributaries enter the reach; however, the Bad River enters the river near the end of this reach in the headwaters of Big Bend Reservoir. Due to the control provided by the downstream Big Bend project, Oahe Dam releases have been extremely variable since the project became fully operational. Minimum mean daily flows of 1,000 cfs or less are not uncommon, while releases near the powerplant capacity of about 55,000 cfs are also frequently made. Since the powerplant became operational, nearly all the releases have been made through the power turbines except during 1997, when releases were very high to evacuate a record flood. A 3,000 cfs minimum Oahe Dam release during daylight hours is normally established in early April to enhance downstream fishing and boating use during the recreation season.

1.4 WATER QUALITY MANAGEMENT CONCERNS AT THE OAHE PROJECT

1.4.1 APPLICABLE WATER QUALITY STANDARDS

1.4.1.1 Oahe Reservoir

The State of South Dakota has designated the following water quality-dependent beneficial uses to Oahe Reservoir in the State's water quality standards: recreation (i.e., immersion and limited-contact), coldwater permanent fish life propagation, domestic water supply, agricultural water supply (i.e., irrigation and stock watering), commerce and industrial waters, and fish and wildlife propagation.

1.4.1.2 Missouri River Downstream of Oahe Dam

The following beneficial uses have been designated by the State in their water quality standards for the Missouri River downstream of Oahe Dam: recreation (i.e., immersion and limited-contact), coldwater permanent fish life propagation, domestic water supply, agricultural water supply (i.e., irrigation and stock watering), commerce and industrial waters, and fish and wildlife propagation.

1.4.2 FEDERAL CLEAN WATER ACT SECTION 303(D) IMPAIRED WATER BODY LISTINGS AND FISH CONSUMPTION ADVISORIES

1.4.2.1 Oahe Reservoir

Pursuant to Section 303(d) of the Federal Clean Water Act (CWA), the State of South Dakota has not placed Oahe Reservoir on the State's Section 303(d) list of impaired waters. The State has not issued a fish consumption advisory for the reservoir. The Cheyenne River Sioux Tribe has issued a fish consumption advisory for mercury for the portions of the Cheyenne River, Moreau River, and Oahe Reservoir that are within their tribal lands.

1.4.2.2 Missouri River Downstream of Oahe Dam

The State of South Dakota has not placed the reach of the Missouri River downstream of Oahe Dam on its Section 303(d) list of impaired waters. The State has not issued a fish consumption advisory for this reach of the Missouri River.

1.4.3 MAINTENANCE OF A "TWO-STORY" RECREATIONAL FISHERY IN OAHE RESERVOIR

Recreation at Oahe Reservoir is of great economic importance to the State of South Dakota, especially with respect to the reservoir's fishery. Oahe Reservoir currently maintains a "two-story" fishery in that the reservoir fishery is comprised of warmwater and coldwater species. The ability of the reservoir to maintain a "two-story" fishery is due to the reservoir's thermal stratification in the summer into a colder bottom region and warmer surface region. Warmwater species present in the reservoir that are recreationally important include walleye (*Sander vitreus*), sauger (*Sander canadensis*), northern pike (*Esox lucius*), smallmouth bass (*Micropterus dolomieu*), catfish (*Ictalurus spp.*), and yellow perch (*Perca *flavescens*). Coldwater species present in the reservoir that are recreationally important include chinook salmon (*Oncorhynchus tshawytscha*). Chinook salmon are maintained in the reservoir through regular stocking. A primary forage fish utilized by all sport fishes in the reservoir is the rainbow smelt (*Osmerus mordax*) – a coldwater species. Since it is a primary forage fish in Oahe Reservoir, fluctuations in the threadfin shad population can have a ripple effect throughout the reservoir's entire recreational sport fishery. The recent pool-level drawdowns of Oahe Reservoir, due to the ongoing drought conditions in the interior western United States have reduced the amount of coldwater habitat available in Oahe Reservoir.

Two water quality parameters, temperature and dissolved oxygen, are of prime importance regarding the maintenance of coldwater fishery habitat in Oahe Reservoir. As the pool level of Oahe Reservoir falls, the amount of coldwater habitat available at lower reservoir depths during summer thermal stratification is reduced. During summer thermal stratification, the reservoir also experiences degradation of dissolved oxygen at lower reservoir depths as accumulated organic matter is decomposed. The situation could be of most concern later in the summer when the reduced volume of colder water combined with the degradation of dissolved oxygen in the deeper water of the reservoir act together to possibly limit the coldwater habitat volume.

2 WATER QUALITY MONITORING CONSIDERATIONS

2.1 WATER QUALITY MONITORING OBJECTIVES

2.1.1 General Monitoring Objectives

The Omaha District has identified four purposes and 12 general monitoring objectives for surface water quality monitoring to facilitate implementation of the District's Water Quality Management Program (USACE, 2008). The water quality monitoring conducted at the Oahe Project over the 3-year period, 2005 through 2007, was implemented to address 6 of the 12 identified monitoring objectives. The six general water quality monitoring objectives that were addressed are:

- Characterize the spatial and temporal distribution of surface water quality conditions at District projects.
- Identify pollutants and their sources that are affecting surface water quality and the aquatic environment at District projects.
- Determine if surface water quality conditions at District projects or attributable to District operations or reservoir regulation (i.e., downstream conditions resulting from reservoir discharges) meet applicable Federal, Tribal, and State water quality standards.
- Determine if surface water quality conditions at District projects or attributable to District operations or reservoir regulation are improving, degrading, or staying the same over time.
- Apply water quality models to assess surface water quality conditions at District projects.
- Collect the information needed to design, engineer, and implement measures or modifications at District projects to enhance surface water quality and the aquatic environment.

2.1.2 Specific Monitoring Objectives

In addition to the six general water quality monitoring objectives, one specific monitoring objective was identified for the intensive water quality surveys of Oahe Reservoir:

1) Collect the information needed to allow application and "full calibration" of the Version 3.2 CE-QUAL-W2 hydrodynamic and water quality model to Oahe Reservoir.

2.2 LIMNOLOGICAL CONSIDERATIONS

2.2.1 Vertical and Longitudinal Water Quality Gradients

The annual temperature distribution represents one of the most important limnological processes occurring within a reservoir. Thermal variation in a reservoir results in temperature-induced density stratification, and an understanding of the thermal regime is essential to water quality assessment. Deep, temperate-zone lakes typically completely mix from the surface to the bottom twice a year (i.e., dimictic). Temperature-zone dimictic lakes exhibit thermally-induced density stratification in the summer and winter months that is separated by periods of "turnover" in the spring and fall (i.e., Oahe Reservoir). This stratification typically occurs through the interaction of wind and solar insolation at the reservoir surface and creates density gradients that can influence reservoir water quality. During the summer, solar insolation has its highest intensity and the reservoir becomes stratified into three zones: 1) epilimnion, 2) metalimnion, and 3) hypolimnion.

<u>Epilimnion</u>: The epilimnion is the upper zone that consists of the less dense, warmer water in the reservoir. It is fairly turbulent since its thickness is determined by the turbulent kinetic energy inputs (e.g., wind, convection, etc.), and a relatively uniform temperature distribution throughout this zone is maintained.

Metalimnion: The metalimnion is the middle zone that represents the transition from warm surface water to cooler bottom water. There is a distinct temperature gradient through the metalimnion. The metalimnion contains the thermocline that is the plane or surface of maximum temperature rate change.

Hypolimnion: The hypolimnion is the bottom zone of the more dense, colder water that is relatively quiescent. Bottom withdrawal or fluctuating water levels in reservoirs, however, may significantly increase hypolimnetic mixing.

Long, dendritic reservoirs with tributary inflows located a considerable distance from the outflow and unidirectional flow from headwater to dam (i.e., Oahe Reservoir) develop gradients in space and time (USACE, 1987). Although these gradients are continuous from headwater to dam, three characteristic zones result: a riverine zone, a zone of transition, and a lacustrine zone (USACE, 1987).

Riverine Zone: The riverine zone is relatively narrow and well mixed, and although water current velocities are decreasing, advective forces are still sufficient to transport significant quantities of suspended particles such as silts, clays, and organic particulate. Light penetration in this zone is minimal and may be the limiting factor that controls primary productivity in the water column. The decomposition of tributary organic loadings often creates a significant oxygen demand, but an aerobic environment is maintained because the riverine zone is generally shallow and well mixed. Longitudinal dispersion may be an important process in this zone.

Zone of Transition: Significant sedimentation occurs through the transition zone, with a subsequent increase in light penetration. Light penetration may increase gradually or abruptly, depending on the flow regime. At some point within the mixed layer of the zone of transition, a compensation point between the production and decomposition of organic matter should be reached. Beyond this point, production of organic matter within the reservoir mixed layer should begin to dominate.

Lacustrine Zone: The lacustrine zone is characteristic of a lake system. Sedimentation of inorganic particulate is low; light penetration is sufficient to promote primary production, with nutrient levels the limiting factor; and production of organic matter exceeds decomposition within the mixed layer. Entrainment of metalimnetic and hypolimnetic water, particulate, and nutrients may occur through internal waves or wind mixing during the passage of large weather fronts. Hypolimnetic mixing may be more extensive in reservoirs than “natural” lakes because of bottom withdrawal. In addition, an intake structure may simultaneously remove water from the hypolimnion and metalimnion.

When tributary inflow enters a reservoir, it displaces the reservoir water. If there is no density difference between the inflow and reservoir waters, the inflow moves as a density current in the form of overflows, interflows, or underflows. Internal mixing is the term used to describe mixing within a reservoir from such factors as wind, Langmuir circulation, convection, Kelvin-Helmholtz instabilities, and outflow (USACE, 1987).

2.2.2 CHEMICAL CHARACTERISTICS OF RESERVOIR PROCESSES

2.2.2.1 Constituents

Some of the most important chemical constituents in reservoir waters that affect water quality are needed by aquatic organisms for survival. These include oxygen, carbon, nitrogen, and phosphorus. Other important constituents are silica, manganese, iron, and sulfur.

Dissolved oxygen: Oxygen is a fundamental chemical constituent of water bodies that is essential to the survival of aquatic organisms and is one of the most important indicators of reservoir water quality conditions. The distribution of dissolved oxygen (DO) in reservoirs is a result of dynamic transfer processes from the atmospheric and photosynthetic sources to consumptive uses by the aquatic biota. The resulting distribution of DO in the reservoir water strongly affects the solubility of many inorganic chemical constituents. Often, water quality control or management approaches are formulated to maintain an aerobic or oxic (i.e., oxygen-containing) environment. Oxygen is produced by aquatic plants (phytoplankton and macrophytes) and is consumed by aquatic plants, other biological organisms, and chemical oxidations. In reservoirs, the DO demand may be divided into two separate but highly interactive fractions: sediment oxygen demand (SOD) and water column oxygen demand.

Sediment oxygen demand: The SOD is typically highest in the upstream area of the reservoir just below the headwater. This is an area of transition from riverine to lake characteristics. It is relatively shallow but stratifies. The loading and sedimentation of organic matter is high in this transition area and, during stratification, the hypolimnetic DO to satisfy this demand can be depleted. If anoxic conditions develop, they generally do so in this area of the reservoir and progressively move toward the dam during the stratification period. The SOD is relatively independent of DO when DO concentrations in the water column are greater than 3 to 4 mg/l, but becomes limited by the rate of oxygen supply to the sediments.

Water column oxygen demand: A characteristic of many reservoirs is a metalimnetic minimum in DO concentrations or negative heterograde oxygen curve (Figure 2.1). Density interflows not only transport oxygen-demanding material into the metalimnion, but can also entrain reduced chemicals from the upstream anoxic area and create additional oxygen demand. Organic matter and organisms from the mixed layer settle at slower rates in the metalimnion because of increased viscosity due to lower temperatures. Since this labile organic matter remains in the metalimnion for a longer time period, decomposition occurs over a longer time, exerting a high oxygen demand. Metalimnetic oxygen depletion is an important process in deep reservoirs. A hypolimnetic oxygen demand generally starts at the sediment/water interface unless underflows contribute organic matter that exerts a significant oxygen demand. In addition to metalimnetic DO depletion, hypolimnetic DO depletion also is important in shallow, stratified reservoirs since there is a smaller hypolimnetic volume of oxygen to satisfy oxygen demands than in deep reservoirs.

Dissolved oxygen distribution: Two basic types of vertical DO distribution may occur in the water column: an orthograde and clinograde DO distribution (Figure 2.1). In the orthograde distribution, DO concentration is a function primarily of temperature, since DO consumption is limited. The clinograde DO profile is representative of more productive, nutrient-rich reservoirs where the hypolimnetic DO concentration progressively decreases during stratification and can occur during both summer and winter stratification periods.

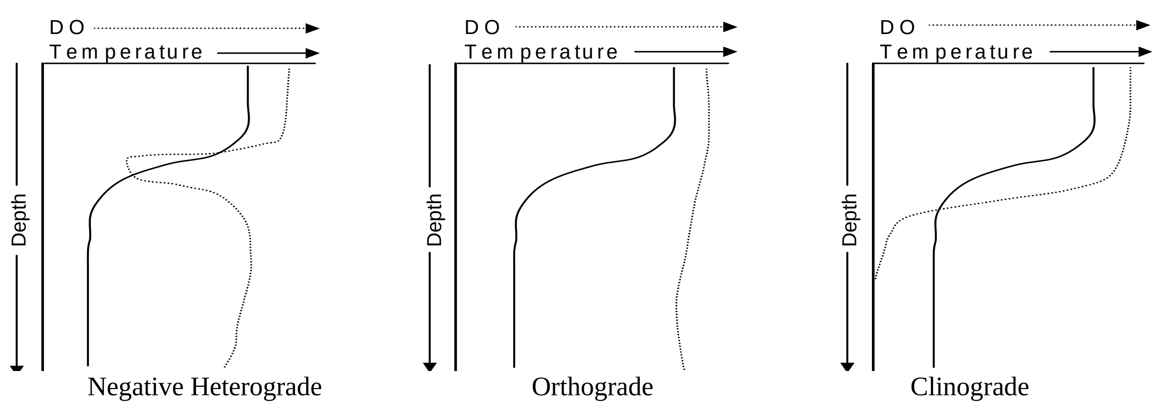

Figure 2.1. Vertical dissolved oxygen concentrations possible in thermally stratified reservoirs.

Inorganic carbon: Inorganic carbon represents the basic building block for the production of organic matter by plants. Inorganic carbon can also regulate the pH and buffering capacity or alkalinity of aquatic systems. Inorganic carbon exists in a dynamic equilibrium in three major forms: carbon dioxide (CO_2), bicarbonate ions (HCO_3), and carbonate ions (CO_3). Carbon dioxide is readily soluble in water and some CO_2 remains in a gaseous form, but the majority of the CO_2 forms carbonic acid that dissociates rapidly into HCO_3 and CO_3 ions. This dissociation results in a weakly alkaline system (i.e., pH $\approx$ 7.1 or 7.2). There is an inverse relationship between pH and CO_2. The pH increases when aquatic plants (phytoplankton or macrophytes) remove CO_2 from the water to form organic matter through photosynthesis during the day. During the night when aquatic plants respire and release CO_2, the pH decreases. The extent of this pH change provides an indication of the buffering capacity of the system. Weakly buffered systems with low alkalinities (i.e., <500 microequivalents per liter) experience larger shifts in pH than well-buffered systems (i.e., >1,000 microequivalents per liter).

Nitrogen: Nitrogen is important in the formulation of plant and animal protein. Nitrogen, similar to carbon, also has a gaseous form. Many species of cyanobacteria can use or fix elemental or gaseous N_2 as a nitrogen source. The most common forms of nitrogen in aquatic systems are ammonia (NH_3-N), nitrite (NO_2-N), and nitrate (NO_3-N). All three forms are transported in water in a dissolved phase. Ammonia results primarily from the decomposition of organic matter. Nitrite is primarily an intermediate compound in the oxidation or nitrification of ammonia to nitrate, while nitrate is the stable oxidation state of nitrogen and represents the other primary inorganic nitrogen form besides NH_3 used by aquatic plants.

Phosphorus: Phosphorus is used by both plants and animals to form enzymes and vitamins and to store energy in organic matter. Phosphorus has received considerable attention as the nutrient controlling algal production and densities and associated water quality problems. The reasons for this emphasis are: phosphorus tends to limit plant growth more than the other major nutrients; phosphorus does not have a gaseous phase and ultimately originates from the weathering of rocks; removal of phosphorus from point sources can reduce the growth of aquatic plants; and the technology for removing phosphorus is more advanced and less expensive than nitrogen removal. Phosphorus is generally expressed in terms of the chemical procedures used for measurement: total phosphorus, particulate phosphorus, dissolved or filterable phosphorus, and soluble reactive phosphorus. Phosphorus is a very reactive element; it reacts with many cations such as iron and calcium and is readily sorbed on particulate matter such as clays, carbonates, and inorganic colloids. Since phosphorus exists in a particulate phase, sedimentation represents a continuous loss from the water column to the sediment. Sediment phosphorus, then, may exhibit longitudinal gradients in reservoirs similar to sediment silt/clay gradients. Phosphorus contributions from sediment under anoxic conditions and macrophyte decomposition are considered internal phosphorus sources or loads, are in a chemical form available for plankton uptake and use, and can represent a major portion of the phosphorus budget.

Silica: Silica is an essential component of diatom algal frustules or cell walls. Silica uptake by diatoms can markedly reduce silica concentrations in the epilimnion and initiate a seasonal succession of diatom species. When silica concentrations decrease below 0.5 mg/l, diatoms generally are no longer competitive with other phytoplankton species.

Other nutrients: Iron, manganese, and sulfur concentrations generally are adequate to satisfy plant nutrient requirements. Oxidized iron (III) and manganese (IV) are quite insoluble in water and occur in low concentrations under aerobic conditions. Under aerobic conditions, sulfur usually is present as sulfate.

2.2.2.2 <u>Anaerobic (Anoxic) Conditions</u>

When dissolved oxygen concentrations in the hypolimnion are reduced to approximately 2 to 3 mg/l, the oxygen regime at the sediment/water interface is generally considered anoxic, and anaerobic processes begin to occur in the sediment interstitial water. Nitrate reduction to ammonium and/or N_2O or N_2 (denitrification) is considered to be the first phase of the anaerobic process and places the system in a slightly reduced electrochemical state. Ammonium-nitrogen begins to accumulate in the hypolimnetic water. The presence of nitrate prevents the production of additional reduced forms such as manganese (II), iron (II), or sulfide species. Denitrification probably serves as the main mechanism for removing nitrate from the hypolimnion. Following the reduction or denitrification of nitrate, manganese species are reduced from insoluble forms (i.e., Mn (IV)) to soluble manganous forms (i.e., Mn (II)), which diffuse into the overlying water column. Nitrate reduction is an important step in anaerobic processes since the presence of nitrate in the water column will inhibit manganese reduction. As the electrochemical potential of the system becomes further reduced, iron is reduced from the insoluble ferric (III) form to the soluble ferrous (II) form, and begins to diffuse into the overlying water column. Phosphorus, in many instances, is also transported in a complexed form with insoluble ferric (III) species so the reduction and solubilization of iron also result in the release and solubilization of phosphorus into the water column. The sediments may serve as a major phosphorus source during anoxic periods and a phosphorus sink during aerobic periods. During this period of anaerobiosis, microorganisms also are decomposing organic matter into lower molecular weight acids and alcohols such as acetic, fulvic, humic, and citric acids and methanol. These compounds may also serve as trihalomethane precursors (low-molecular weight organic compounds in water; i.e., methane, formate acetate), which, when subject to chlorination during water treatment, form trihalomethanes, or THMs (carcinogens). As the system becomes further reduced, sulfate is reduced to sulfide, which begins to appear in the water column. Sulfide will readily combine with soluble reduced iron (II), however, to form insoluble ferrous sulfide, which precipitates out of solution. If the sulfate is reduced to sulfide and the electrochemical potential is strongly reducing, methane formation from the reduced organic acids and alcohols may occur. Consequently, water samples from anoxic depths will exhibit these chemical characteristics.

Anaerobic processes are generally initiated in the upstream portion of the hypolimnion where organic loading from the inflow is relatively high and the volume of the hypolimnion is minimal, so oxygen depletion occurs rapidly. Anaerobic conditions are generally initiated at the sediment/water interface and gradually diffuse into the overlying water column and downstream toward the dam. Anoxic conditions may also develop in a deep pocket near the dam due to decomposition of autochthonous organic matter settling to the bottom. This anoxic pocket, in addition to expanding vertically into the water column, may also move upstream and eventually meet the anoxic zone moving downstream.

Anoxic conditions are generally associated with the hypolimnion, but anoxic conditions may occur in the metalimnion. The metalimnion may become anoxic due to microbial respiration and decomposition of plankton settling into the metalimnion, microbial metabolism of organic matter entering as an interflow, or through entrainment of anoxic hypolimnetic water from upper reservoir reaches.

2.2.3 BIOLOGICAL CHARACTERISTICS AND PROCESSES

2.2.3.1 <u>Microbiological</u>

The microorganisms associated with reservoirs may be categorized as pathogenic or nonpathogenic. Pathogenic microorganisms are of a concern from a human health standpoint and may limit recreational and other uses of reservoirs. Nonpathogenic microorganisms are important in that they often serve as decomposers of organic matter and are a major source of carbon and energy for a reservoir. Microorganisms generally inhabit all zones of the reservoir as well as all layers. Seasonally high concentrations of bacteria will occur during the warmer months, but they can be diluted by high discharges. Anaerobic conditions enhance growth of certain bacteria while aeration facilitates the use of bacterial food sources. Microorganisms, bacteria in particular, are responsible for mobilization of contaminants from sediments.

2.2.3.2 Photosynthesis

Oxygen is a by-product of aquatic plant photosynthesis, which represents a major source of oxygen for reservoirs during the growing season. Oxygen solubility is less during the period of higher water temperatures, and diffusion may also be less if wind speeds are lower during the summer than in the spring or fall. Biological activity and oxygen demand typically are high during thermal stratification, so photosynthesis may represent a major source of oxygen during this period. Oxygen supersaturation in the euphotic zone can occur during periods of high photosynthesis.

2.2.3.3 Plankton

Phytoplankton influence dissolved oxygen and suspended solids concentrations, transparency, taste and odor, aesthetics, and other factors that affect reservoir uses and water quality objectives. Phytoplankton are a primary source of organic matter production and form the base of the autochthonous food web in many reservoirs since fluctuating water levels may limit macrophyte and periphyton production. Phytoplankton can be generally grouped as diatoms, green algae, cyanobacteria, or cryptomonad algae. Chlorophyll *a* represents a common variable used to estimate phytoplankton biomass.

Seasonal succession of phytoplankton species is a natural occurrence in reservoirs. The spring assemblage is usually dominated by diatoms and cryptomonads. Silica depletion in the photic zone and increased settling as viscosity decreases because of increased temperatures usually result in green algae succeeding the diatoms. Decreases in nitrogen or a decreased competitive advantage for carbon at higher pH may result in cyanobacteria succeeding the green algae during summer and fall. Diatoms generally return in the fall, but cyanobacteria, greens, or diatoms may cause algae blooms following fall turnover when hypolimnetic nutrients are mixed throughout the water column. The general pattern of seasonal succession of phytoplankton is fairly constant from year to year. However, hydrologic variability, such as increased mixing and delay in the onset of stratification during cool, wet spring periods, can maintain diatoms longer in the spring and shift or modify the successional pattern of algae in reservoirs.

Phytoplankton grazers can reduce the abundance of algae and alter their successional patterns. Some phytoplankton species are consumed and assimilated more readily and are preferentially selected by consumers. Single-celled diatom and green algae species are readily consumed by zooplankton, while filamentous cyanobacteria are avoided by zooplankters. Altering the fish population can result in a change in the zooplankton population that can affect the phytoplankton population.

2.2.3.4 Organic Carbon and Detritus

Total organic carbon (TOC) is composed of dissolved organic carbon (DOC) and particulate organic carbon (POC). Detritus represents that portion of the POC that is nonliving. Nearly all the TOC of natural waters consists of DOC and detritus, or dead POC. The processes of decomposition and consumption of TOC are important in reservoirs and can have a significant affect on water quality.

DOC and POC are decomposed by microbial organisms. This decomposition exerts an oxygen demand that can remove dissolved oxygen from the water column. During stratification, the metalimnion and hypolimnion become relatively isolated from sources of dissolved oxygen, and depletion can occur through organic decomposition. There are two major sources of this organic matter: allochthonous (i.e., produced outside the reservoir and transported in) and autochthonous (i.e., produced within the reservoir). Allochthonous organic carbon in small streams may be relatively refractory since it consists of decaying terrestrial vegetation that has washed or fallen into the stream. Larger rivers, however, may contribute substantial quantities of riverine algae or periphyton that decompose rapidly and can exert a significant oxygen demand. Autochthonous sources include dead plankton settling from the mixed layers and macrophyte fragments and periphyton transported from the littoral zone. These sources are also rapidly decomposed.

POC and DOC absorbed onto sediment particles may serve as a major food source for aquatic organisms. The majority of the phytoplankton production enters the detritus food web with a minority being grazed by primary consumers (USACE, 1987). While autochthonous production is important in reservoirs, typically as much as three times the autochthonous production may be contributed by allochthonous material (USACE, 1987).

2.2.4 BOTTOM WITHDRAWAL RESERVOIRS

Bottom withdrawal structures are located near the deepest part of a reservoir. Bottom withdrawal removes hypolimnetic water and nutrients and may promote movement of interflows or underflow into the hypolimnion. They release coldwaters from the deep portion of the reservoir; however, these waters may be hypoxic during periods of stratification. Bottom outlets can cause density interflows or underflows (e.g., flow laden with sediment or dissolved solids) through the reservoir and generally provide little or no direct control over release water quality.

The intake structure for the power tunnels at Oahe Dam withdraws water at a “mid-level” depth from Oahe Reservoir. The intake structure consists of seven individual control towers 145 feet high that have inverts for water intake set at elevation 1524 ft-msl. The intake invert elevation of 1524 ft-msl is approximately 110 feet above bottom in the deepest area of the reservoir, and would be at a depth of about 84 feet when the reservoir is at the top of the Carryover Multiple Use Zone (i.e., elevation 1607.5 ft-msl). Depending on the reservoir pool elevation, water drawn into the power tunnel intakes can come from the epilimnion, metalimnion, or hypolimnion during summer thermal stratification of the reservoir.

2.3 APPLICATION OF THE CE-QUAL-W2 WATER QUALITY MODEL TO THE MISSOURI RIVER MAINSTEM SYSTEM PROJECTS

Water quality data must be applied to understand and manage water resources effectively. Application of appropriate mathematical models promotes efficient and effective use of data. Models are powerful tools for guiding project operations, refining water quality sampling programs, planning project modifications, evaluating management scenarios, improving project benefits, and illuminating new or understanding complex phenomena. CE-QUAL-W2 is a “state-of-the-art” water quality model that can greatly facilitate addressing reservoir water quality management issues.

CE-QUAL-W2 is a water quality and hydrodynamic model in two dimensions (longitudinal and vertical) for rivers, estuaries, lakes, reservoirs, and river basin systems. CE-QUAL-W2 models basic physical, chemical, and biological processes such as temperature, nutrient, algae, dissolved oxygen, organic matter, and sediment relationships. Version 1.0 of the model was developed by the Corps’ Water Quality Modeling Group at the Waterways Experiment Station in the late 1980’s. The current model release is Version 3.2 and is supported by the Corps’ Engineer Research and Development Center (ERDC) and Portland State University.

2.3.1 PAST APPLICATION OF THE CE-QUAL-W2 MODEL

Version 2.0 of the CE-QUAL-W2 model was applied to four of the upper Mainstem System Projects in the early 1990's (i.e., Fort Peck, Garrison, Oahe, and Fort Randall). The application of the model was part of the supporting technical documentation of the Environmental Impact Statement (EIS) that was prepared for the Missouri River Master Water Control Manual Review and Update Study. The results of the model application were included as an Appendix to the Review and Update Study – "Volume 7B: Environmental Studies, Reservoir Fisheries, Appendix C – Coldwater Habitat Model, Temperature and Dissolved Oxygen Simulations for the Upper Missouri River Reservoirs" (Cole et. al., 1994). The report (Cole et. al, 1994) provided results of applying the model to the four reservoirs regarding the effects of operational changes on reservoir coldwater fish habitat. This early application of the model represents the best results that could be obtained based on the model version and water quality data available at that time, and it provided predictive capability for coldwater fish habitat regarding two system operational variables of concern – end-of-month stages and monthly average releases.

Although application of the CE-QUAL-W2 (Version 2.0) model met its intended purpose at the time, a lack of available water data placed limitations on its full utilization. These limitations were discussed in the Master Water Control Review and Update Study report (Cole et. al, 1994). The following excerpts are taken from that report:

> *"Typically, dissolved oxygen (DO) is modeled along with a full suite of water quality variables including algal/nutrient interactions. Lack of available algal/nutrient data necessitated a different approach. DO was assumed to be a function of sediment and water column oxygen demands which were adjusted during calibration to reproduce the average DO depletion during summer stratification. The drawback to this approach is that operational changes which might affect algal/nutrient interactions cannot be predicted. Results from this study show only how physical factors relating to changes in reservoir stage and discharge affect DO."*
>
> *"As a result, model predictions during scenario runs represent only how physical factors affect DO and do not include the effects of reservoir operations on algal/nutrient dynamics and their effects on DO. To include algal/nutrient effects would require at least one year's worth of detailed algal/nutrient data for each reservoir that were not and could not be made available during the time frame of this study."*
>
> *"Steps should be taken to obtain a suitable database that can be used to calibrate the entire suite of water quality algorithms in the model. It is almost a certainty that water quality issues will remain important in the future."*

The current version of the CE-QUAL-W2 model (Version 3.2) has incorporated numerous enhancements over the Version 2.0 model that was applied to the four Mainstem System Projects in the early 1990's. These enhancements, among other things, include improvements to the numerical solution scheme, water quality algorithms, two-dimensional modeling of the waterbasin, code efficiencies, and user-model interface. Communication with the author of the past application of the Version 2.0 model to the Mainstem System Projects and current model support personnel indicated that the Omaha District should pursue implementing Version 3.2 of the model (personal communication, Thomas M. Cole, USACE/ERDC).

2.3.2 FUTURE APPLICATION OF THE CE-QUAL-W2 MODEL

As part of its Water Quality Management Program, the Omaha District initiated the application of the CE-QUAL-W2 (Version 3.2) model to the Mainstem System Projects. The District is approaching the model application as an ongoing, iterative process. Data will be collected, and the model will be run and continuously calibrated as new information is gathered. The goal is to have a fully functioning model in place for all the Mainstem System Projects that meets the uncertainty requirements of decision-makers.

The current plan for applying the model to a single project will encompass a 5-year period. During years 1 through 3 an intensive water quality survey will be conducted to collect the water quality data needed to fully apply the model. The water quality data will be compiled and a Special Water Quality Report assessing the water quality data will be compiled in year 4 (this report). Application and calibration of the model will be initiated in year 5. Once the model has been applied and calibrated, a Water Quality Modeling report will be prepared documenting the application of the model to the specific reservoir. The calibrated model will then be used to facilitate the development of a Project-Specific Water Quality Report and water quality management objectives for the specific reservoir. The current plan is to stagger the application of the model by annually beginning the application process at a different Mainstem System project. The current order for applying the model to the Projects is: 1) Garrison Project, 2) Fort Peck Project, 3) Oahe Project, 4) Fort Randall Project, 5) Big Bend Project, and 6) Gavins Point Project. Eventually it is hoped that the CE-QUAL-W2 models developed for each of the Projects can be linked and used to make integrated water quality management decisions throughout the Mainstem System.

2.3.3 CURRENT APPLICATION OF THE CE-QUAL-W2 MODEL TO OAHE RESERVOIR

The 3-year intensive water quality survey was conducted at the Oahe Project during 2005 through 2007, and the application and calibration of the model to Oahe Reservoir is planned for 2010. The Oahe Project will be the third Mainstem System Project on which the Version 3.2 CE-QUAL-W2 model is applied. Model application will focus on modifying the earlier developed reservoir bathymetry files, refining the calibration of outflow water quality conditions, and activating the model's water quality algorithms. Much more detailed outflow data regarding monitored water quality conditions now exists to refine the calibration of the model. The water quality algorithms that describe the nutrient/algae/dissolved oxygen interactions will be calibrated. The goals are to have the model mechanistically determine reservoir dissolved oxygen levels and to use the model's predictive capabilities to evaluate factors influencing the occurrence of dissolved oxygen in Oahe Reservoir. A Water Quality Modeling Report will be prepared at a future date describing the application and calibration of the CE-QUAL-W2 Version 3.2 model to Oahe Reservoir.

3 DATA COLLECTION METHODS

3.1 DATA COLLECTION DESIGN

3.1.1 MONITORING LOCATIONS

The Omaha District collected water quality data at 10 locations at the Oahe Project during the period 2005 through 2007. Of the 10 locations, 7 were located on Oahe Reservoir, 2 were located on the major tributary inflows to the reservoir (i.e., Missouri River and Cheyenne River), and 1 was located at the Oahe Dam powerhouse. Due to low pool levels during the 2005 through 2007 period, the upper reaches of Oahe Reservoir terminated near the SD/ND state line. Table 3.1 describes the monitoring locations in greater detail, and Figure 3.1 shows their locations.

3.1.2 MONITORING STATION TYPES

The monitoring stations where water quality data were collected were categorized into three types: 1) reservoir (lake), 2) inflow, and 3) outflow (Table 3.1). All of the reservoir stations were meant to represent "deepwater" pelagic conditions and were established at the deepest part of the reservoir with regards to the area being monitored. The seven reservoir monitoring stations (i.e., L1 - L7) were approximately equally spaced along the longitudinal axis of Oahe Reservoir from near the dam to the upper reaches of the reservoir near Mobridge, South Dakota. These stations were located along the submerged old Missouri River channel with the farthermost of the seven stations separated by 123 miles (Figure 3.1). The two inflow stations were located on the Missouri River at Bismarck, North Dakota and the Cheyenne River just upstream of its confluence with Oahe Reservoir (Figure 3.1). The single outflow station was located in the Oahe Dam powerplant. Water quality data collected at this station consisted of monitoring the quality of the water being discharged through the dam's turbines. Depending on pool elevation, the monitoring stations are believed to be associated with the following zones: Lacustrine Zone (L1, L2, L3, L4, OF1), Zone of Transition (L4, L5, L6), and Riverine Zone (L6, L7, NF1).

Table 3.1. Location and description of monitoring stations that were sampled by the Omaha District for water quality at the Oahe Project during the period 2005 through 2007.

Station Number	Station Alias	Name	Location	Station Type	Latitude	Longitude
OAHNFMORR1	NF1	Missouri River at Bismarck, ND	At U.S. Interstate 90 Bridge Crossing	Boundary Conditions Tributary Inflow	-----	-----
OAHNFCHYR1	NF2	Cheyenne River near, Eagle Butte, SD	At SD Highway 63 Bridge Crossing	Boundary Conditions Tributary Inflow	-----	-----
OAHLK1073A	L1	Lake Oahe – Near Dam	Reservoir, Deepwater	In-Pool Conditions	N44 27' 45.573" (N44.462659)	W100 25' 18.493" (W100.421804)
OAHLK1090DW	L2	Lake Oahe – Cow Creek Area	Reservoir, Deepwater	In-Pool Conditions	N44 33' 09.445" (N44.552624)	W100 32' 13.086" (W100.536968)
OAHLK1110DW	L3	Lake Oahe – Cheyenne River Area	Reservoir, Deepwater	In-Pool Conditions	N44 46' 15.266" (N44.770907)	W100 43' 02 286" (W100.717302)
OAHLK1135DW	L4	Lake Oahe – Sutton Bay Area	Reservoir, Deepwater	In-Pool Conditions	N44 52' 08.105" (N44.868918)	W100 23' 35.483" (W100.393190)
OAHLK1153DW	L5	Lake Oahe – Whitlocks Bay Area	Reservoir, Deepwater	In-Pool Conditions	N45 01' 51.329" (N45.030925)	W100 16' 43.801" (W100.278834)
OAHLK1176DW	L6	Lake Oahe – Swan Creek Area	Reservoir, Deepwater	In-Pool Conditions	N45 19' 46.832" (N45.329676)	W100 18' 36.616" (W100.310171)
OAHLK1196DW	L7	Lake Oahe – Mobridge Area	Reservoir, Deepwater	In-Pool Conditions	N45 32' 29.243" (N45.541456)	W100 29' 08.844" (W100.485790)
OAHPP1	OF1	Oahe Powerplant	Oahe Powerplant	Boundary Conditions Reservoir Outflow	-----	-----

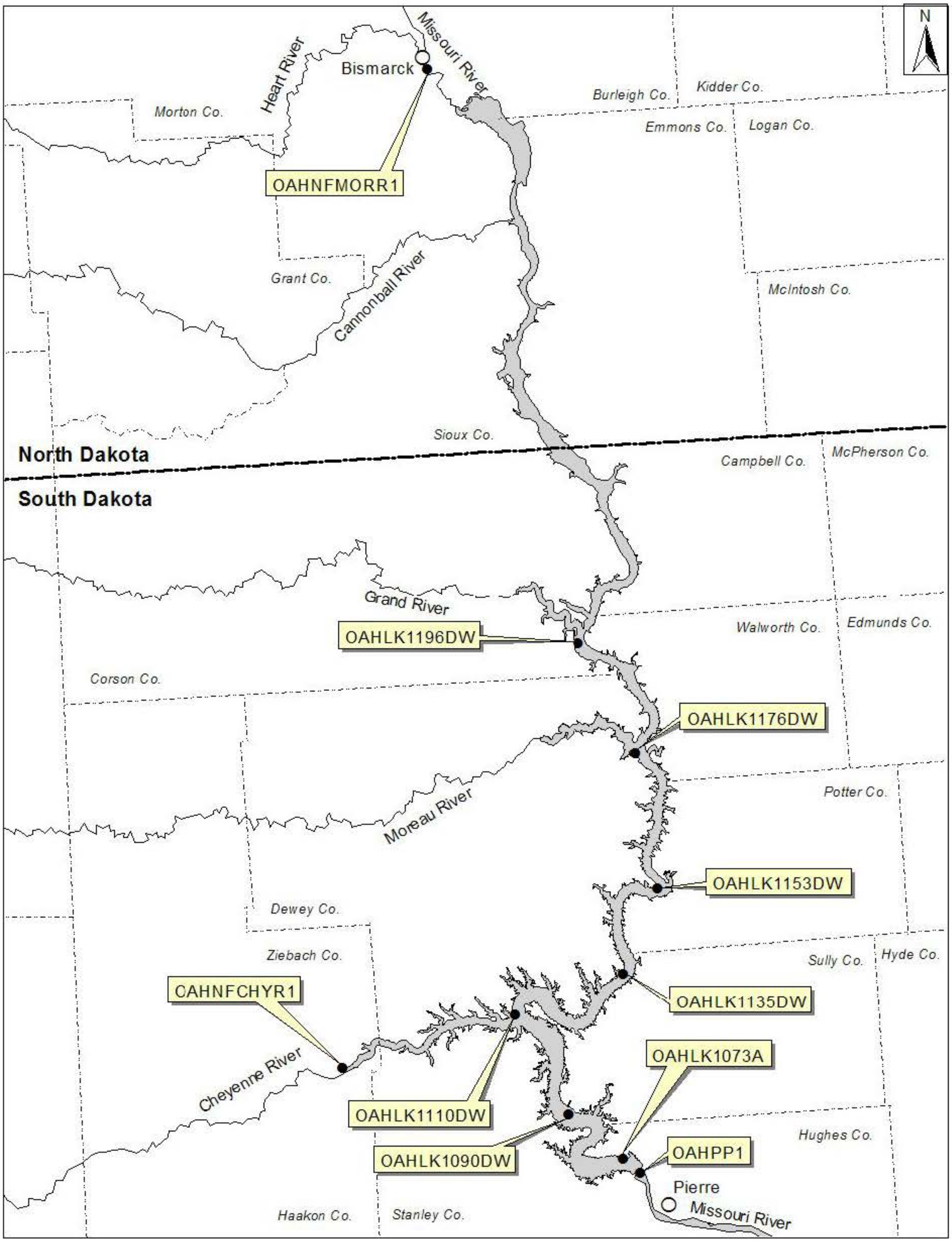

Figure 3.1. Location of sites where water quality monitoring was conducted by the Omaha District at the Oahe Project during the period 2005 through 2007.

3.1.3 Measurements, Sample Types, and Collection Frequency

3.1.3.1 Reservoir Monitoring Stations

Monitoring at the reservoir monitoring stations consisted of field measurements and collection of discrete-depth "grab" samples for laboratory analysis. Field measurements consisted of depth-profiles for selected parameters and a surface Secchi depth measurement. Two depth-discrete grab samples, near-surface (i.e., ½ the measured Secchi depth) and near-bottom (i.e., within 2 meters of the reservoir bottom), were collected. Measurements and samples were collected monthly during the period May through September.

3.1.3.2 Inflow Monitoring Stations

Monitoring at the two inflow stations (i.e., NF1 and NF2) consisted of field measurements and collection of grab samples. A near-surface grab sample was collected from near the bank in an area of faster current. Monitoring at the two stations occurred monthly during the period May through September.

Through an agreement with the U.S. Geological Survey (USGS), a water temperature monitoring probe was added to the USGS's gage on the Missouri River at Bismarck, North Dakota (i.e., USGS gage site 06342500). Beginning in October 2004, hourly water temperature measurements were recorded at the site.

3.1.3.3 Outflow Monitoring Station

Monitoring at the Oahe powerhouse consisted of year-round hourly logging of water quality measurements and monthly collection of grab samples. Measurements and samples were taken from a "flow-chamber" drawing water from the "raw-water" supply line in the powerplant. The raw-water supply line is a 10-inch pipe that collects water through a header that draws from each of the seven power tunnels. Depending on which tunnel is tapped, the water provided to the monitoring site "flow-chamber" travels from 200 to 800 feet through the 10-inch raw-water supply line. Water provided to the monitoring site flow-chamber from the 10-inch raw-water supply line flows through a 6-inch pipe for 60 feet and finally through a ¾-inch pipe for an additional 60 feet.

3.1.4 Parameters Measured and Analyzed

3.1.4.1 Water Quality Parameters

The water quality parameters that were measured and analyzed at the various monitoring stations are given in Table 3.2.

3.1.4.2 Explanatory Variables

Explanatory variables that were quantified included inflow discharge, outflow discharge, and reservoir pool elevation. Inflow discharge at station NF1 was taken as the recorded discharge at the USGS gage (06342500) on the Missouri River at Bismarck, ND. Inflow discharge at station NF2 was determined from the USGS gage (06438500) on the Cheyenne River near Plainview, SD. Outflow discharge from Oahe Dam and the pool elevation of Oahe Reservoir were obtained from Oahe Project records.

Table 3.2. Parameters measured and analyzed at the various monitoring stations.

Parameter	L1, L3, L5, L7	L2, L4, L6	NF1, NF2	OF1
Dissolved Solids, Total	✓		✓	✓
Organic Carbon, Total (TOC)	✓		✓	✓
Orthophosphorus, Dissolved	✓		✓	✓
Phosphorus, Total	✓		✓	✓
Dissolved Phosphorus, Total	✓		✓	✓
Nitrate-Nitrite as N, Total	✓		✓	✓
Ammonia as N, Total	✓		✓	✓
Kjeldahl Nitrogen, Total	✓		✓	✓
Suspended Solids, Total	✓		✓	✓
Alkalinity	✓		✓	✓
Sulfate	✓		✓	✓
Chlorophyll a	✓			
Phytoplankton Biomass and Taxa Identification	✓			
Iron, Total and Dissolved	✓		✓	✓
Manganese, Total and Dissolved	✓		✓	✓
Metals and Hardness			✓ (NF1)	✓
Pesticide Scan			✓ (NF1)	✓
Microcystins	✓			
Secchi Depth/Transparency	✓	✓		
Field Measurements (Hydrolab)**	✓ (Depth Profile)	✓ (Depth Profile)	✓ (Near Surface)	✓ (Grab Sample)
Continuous Monitoring ("Hydrolab")***				✓

Note: Not all parameters were monitored at all the sites indicated.

** Hydrolab field measurements included: water temperature, dissolved oxygen (mg/l and % saturation), pH, conductivity, ORP, turbidity, and chlorophyll *a*. Depth profile measurements taken at 1-meter intervals from the reservoir surface to the bottom.

*** Continuous monitored parameters include temperature, dissolved oxygen (mg/l and % saturation), and conductivity.

3.2 WATER QUALITY MEASUREMENT AND SAMPLING METHODS

3.2.1 FIELD MEASUREMENTS

Depth-profile and surface measurements for water temperature, dissolved oxygen (mg/l and % saturation), pH, conductivity, Oxidation-Reduction potential (ORP), turbidity, and chlorophyll *a* were taken using a "Hydrolab". Profile measurements were taken at 1-meter intervals. The Hydrolab was operated as specified in the USACE – Water Quality Unit's Standard Operating Procedures (SOPs) Number WQ-21201, "Using a Hydrolab 4, 4a, and 5 to Directly Measure Water Quality" (USACE, 2006). Secchi transparency was measured in accordance with the USACE – Water Quality Unit's SOP Number WQ-21202, "Determining Secchi Depth" (USACE, 2004b).

3.2.2 WATER QUALITY SAMPLE COLLECTION AND ANALYSIS

All water quality samples were collected in accordance with the USACE – Water Quality Unit's SOP Number WQ-21101, "Collection of Surface Water Samples" (USACE, 2003). Surface grab samples were collected by dipping a rinsed plastic churn bucket just below the surface (i.e., approximately 6 inches below the surface). Depth-discrete grab samples were collected with a Kemmerer sampler that was lowered to the desired sampling depth, triggered, and retrieved to the boat.

3.3 ANALYTICAL METHODS

Laboratory analyses of all collected water quality samples were done by either: 1) the Corps' Engineer Research and Development Center (ERDC), Environmental Chemistry Branch Laboratory in Omaha, Nebraska; or 2) the District's contract laboratory, Midwest Laboratories, in Omaha, Nebraska. The analytical methods, detection limits, and reporting limits for the analysis of the collected water quality samples are given in Table 3.3. Analysis of the collected plankton samples was done by a laboratory under contract to the ERDC Omaha Laboratory or Midwest Laboratories.

Table 3.3. Methods, detection limits, and reporting limits for laboratory analyses.

Analyte	Method	Detection Limit	Reporting Limit
Alkalinity, Total	EPA - 310.2	7 mg/l	20 mg/l
Nitrate/Nitrite, Total as N	EPA - 353.2	0.02 mg/l	0.1 mg/l
Ammonia, Total as N	EPA - 350.1	0.01 mg/l	0.1 mg/l
Kjeldahl Nitrogen, Total as N	EPA - 351.2	0.1 mg/l	0.2 mg/l
Phosphorus, Total as P	EPA - 365.4	0.01 mg/l	0.02 mg/l
Phosphorus, Total Dissolved	EPA - 365.4	0.01 mg/l	0.02 mg/l
Orthophosphorus	EPA - 300.0 / 365.1	0.01 mg/l	0.03 mg/l
Sulfate, Total	EPA - 300.0 / 375.2	0.01 mg/l / 6 mg/l	0.1 mg/l / 20 mg/l
Dissolved Solids, Total	EPA - 160.1	5 mg/l	10 mg/l
Suspended Solids, Total	EPA - 160.2	4 mg/l	10 mg/l
Organic Carbon, Total (TOC)	EPA - 9060	0.05 mg/l	0.25 mg/l
Dissolved Metals:	EPA - 6010B		
Antimony		6 ug/l	20 ug/l
Arsenic		3 ug/l	15 ug/l
Beryllium, Cadmium		0.5 ug/l	2 ug/l
Calcium		100 ug/l	300 ug/l
Chromium, Copper, Lead		2 ug/l	10 ug/l
Nickel, Zinc		3 ug/l	10 ug/l
Magnesium		40 ug/l	120 ug/l
Silver		1 ug/l	5 ug/l
Thallium		6 ug/l	30 ug/l
Mercury, dissolved and total	EPA - 7470A	0.02 ug/l	0.1 ug/l
Iron, total and dissolved	EPA - 6010B	40 ug/l	120 ug/l
Manganese, total and dissolved	EPA - 6010B	2 ug/l	10 ug/l
Selenium, total	EPA - 6010B	4 ug/l	20 ug/l
Chlorophyll *a*	SM - 10200H2	1 ug/l	3 ug/l
Pesticide scan*:	EPA - 507	0.05 ug/l	0.1 ug/l
Immunoassay – Microcystins	Rapid Assay	0.2 ug/l	1 ug/l

* Pesticide scan included: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, cycloate, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, phorate, profluralin, prometon, propachlor, propazine, simazine, terbufos, triallate, trifluralin, and vernolate.

4 DATA ASSESSMENT METHODS

4.1 EXISTING WATER QUALITY (2005 THROUGH 2007)

4.1.1 GENERAL WATER QUALITY CONDITIONS

Statistical analyses were performed on the water quality monitoring data collected at reservoir, inflow, and outflow sites during the period 2005 through 2007. Descriptive statistics (i.e., mean, median, minimum, maximum) were calculated to describe central tendencies and the range of observations. Where appropriate, monitoring results were compared to defined water quality standards criteria for the State of South Dakota.

Spatial variation of selected water quality parameters in Oahe Reservoir was evaluated. Longitudinal contour plots were constructed for water temperature, dissolved oxygen, and turbidity to display likely conditions in Oahe Reservoir from its upper reaches to Oahe Dam. The longitudinal contour plots were constructed using the "Hydrologic Information Plotting Program" included in the "Data Management and Analysis System for Lakes, Estuaries, and Rivers" (DASLER-X) software developed by HydroGeoLogic, Inc. (Hydrogeologic Inc., 2005). Secchi depth measurements collected along Oahe Reservoir were evaluated and are displayed using a box plot. The variation of selected parameters with depth were evaluated at site L1 by comparing near-surface and near-bottom collected samples using box plots.

The phytoplankton community was assessed based on collected grab samples. The collected phytoplankton samples were analyzed by a contract laboratory. Laboratory analyses consisted of identification of phytoplankton taxa to the lowest practical level and quantification of taxa biovolume. These results were used to determine the relative abundance of phytoplankton taxa at the division level based on the measured biovolumes, and the occurrence of dominant taxa. Dominant taxa were defined as taxa that comprised more than 10 percent of the total biovolume of the collected sample. Collected near-surface reservoir water quality samples were also analyzed for the cyanobacterial toxin microcystins.

4.1.2 TROPHIC STATUS

Reservoirs are commonly classified or grouped by trophic or nutrient status. The natural progression of reservoirs through time is from an oligotrophic (i.e., low nutrient/low productivity) through a mesotrophic (i.e., intermediate nutrient/intermediate productivity) to a eutrophic (i.e., high nutrient/high productivity) condition. The prefixes "ultra" and "hyper" are sometimes added to oligotrophic or eutrophic, respectively, as additional degrees of trophic status. The tendency toward the eutrophic, or nutrient-rich, status is common to all impounded waters. The eutrophication, or enrichment process, can adversely impact water quality conditions in reservoirs (e.g., increased occurrence of algal blooms, noxious odors, and fish kills; reduced water clarity; reduced hypolimnetic dissolved oxygen concentrations; etc.). Eutrophication of reservoirs can be accelerated by nutrient additions through cultural activities (e.g., point-source discharges and nonpoint sources such as runoff from cropland, livestock facilities, urban areas, etc.).

A Trophic State Index (TSI) can be calculated as described by Carlson (1977). TSI values are determined from Secchi disk transparency, total phosphorus, and chlorophyll *a* measurements. Values for these three parameters are converted to an index number ranging from 0 to 100 according to the following equations:

$$TSI(\text{Secchi Depth}) = TSI(SD) = 10[6 - (\ln SD/\ln 2)]$$
$$TSI(\text{Chlorophyll } a) = TSI(Chl) = 10[6 - ((2.04\text{-}0.68 \ln Chl)/\ln 2)]$$
$$TSI(\text{Total Phosphorus}) = TSI(TP) = 10[6 - (\ln (48/TP)/\ln 2)]$$

Accurate TSI values from total phosphorus depend on the assumptions that phosphorus is the major limiting factor for algal growth and that the concentrations of all forms of phosphorus present are a function of algal biomass. Accurate TSI values from Secchi disk transparency depend on the assumption that water clarity is primarily limited by phytoplankton biomass. Carlson indicates that the chlorophyll TSI value may be a better indicator of a lake's trophic condition during mid-summer when algal productivity is at its maximum, while the total phosphorus TSI value may be a better indicator in the spring and fall when algal biomass is below its potential maximum. Calculation of TSI values from data collected from a lake's epilimnion during summer stratification provide the best agreement between all of the index parameters and facilitate comparisons between lakes. Care should be taken if a TSI average score is calculated from the three individual parameter TSI values. If significant differences exist between parameter TSI values, the calculated average value may not be indicative of the trophic condition estimated by the individual parameter values. With this in mind, a TSI average value [TSI(Avg)] calculated as the average of the three individually determined TSI values [i.e., TSI(SD), TSI(Chl), and TSI(TP)] is used by the Omaha District as an overall indicator of a reservoir's trophic state. The Omaha District uses the criteria defined in Table 4.1 for determining reservoir trophic status from TSI values.

Table 4.1. Reservoir trophic status based on calculated Trophic State Index (TSI) values.

TSI	Trophic Condition
0-35	Oligotrophic
36-50	Mesotrophic
51-55	Moderately Eutrophic
56-65	Eutrophic
66-100	Hypereutrophic

In addition to classifying lakes, the TSI can serve as an internal check on the assumptions about the relationships among various components of a lake's ecosystem. Carlson states that that the three TSI parameters, when transformed to the trophic scale, should have similar values. Any divergence from this value by one or more of the parameters may provide insights into a lake's water quality dynamics (e.g., is the lake phosphorus limited, is water clarity limited by algae or nonalgal particulate matter, etc.)

Existing trophic conditions were assessed for Oahe Reservoir based on the monitoring conducted during the 3-year period 2005 through 2007 period. The data evaluated consisted of Secchi depth measurements and total phosphorus and chlorophyll *a* analytical results obtained at the reservoir sites L1, L3, L5, and L7. TSI values were calculated and compared to the above criteria.

4.1.3 TIME-SERIES PLOTS OF FLOW, WATER TEMPERATURE, AND DISSOLVED OXYGEN OF WATER DISCHARGED THROUGH OAHE DAM

Time series plots were prepared for conditions measured at the Oahe Dam powerhouse during the 2005 through 2007 period. Discharge was plotted with hourly temperature and dissolved oxygen measurements. Plots were for measurements taken from the "raw water" supply line.

4.2 ESTIMATING THE OCCURRENCE OF COLDWATER HABITATS IN OAHE RESERVOIR

4.2.1 COLDWATER HABITAT CRITERIA – WATER TEMPERATURE AND DISSOLVED OXYGEN

Water temperature and dissolved oxygen levels are primary water quality factors that determine the suitability of water for coldwater aquatic life. Water quality standards for the protection of aquatic life (i.e., water temperature and dissolved oxygen criteria) usually include different levels of protection based on habitat types, life stages (i.e., eggs, fry, juvenile, and adults), and acute and chronic effects. To protect waters for coldwater permanent fish life propagation, the State of South Dakota has promulgated the following numeric water quality standards criteria for water temperature and dissolved oxygen: water temperature ≤ 65°F (18.3°C), and dissolved oxygen ≥ 6 mg/l (≥ 7 mg/l in spawning areas during spawning season). To protect waters for coldwater marginal fish life propagation, the State has promulgated the following numeric water quality standards criteria for water temperature and dissolved oxygen: water temperature ≤ 75°F (23.9°C), and dissolved oxygen ≥ 5.0 mg/l.

4.2.2 DEFINITION OF COLDWATER HABITAT TYPES FOR OAHE RESERVOIR

For evaluating the coldwater habitat present in Oahe Reservoir, two types of coldwater habitat were defined for use in this report based on water temperature and dissolved oxygen concentrations (Table 4.2). Coldwater habitat is defined as water having a temperature of ≤ 18.3°C and a dissolved oxygen concentration of ≥ 6.0 mg/l. Marginal coldwater habitat is defined as water having a temperature of ≤ 23.9°C and a dissolved oxygen concentration of ≥ 5.0 mg/l.

Table 4.2. Coldwater habitat types defined for evaluation of temperature and dissolved oxygen conditions in Oahe Reservoir.

Habitat Type	Water Temperature Criteria	Dissolved Oxygen Criteria
Coldwater	≤ 18.3°C	≥ 6.0 mg/l
Marginal Coldwater	≤ 23.9°C	≥ 5.0 mg/l

4.2.3 VOLUME ESTIMATION OF COLDWATER HABITATS IN OAHE RESERVOIR

The Oahe Reservoir was divided into seven regions represented by the seven reservoir monitoring sites (i.e., L1, L2, L3, L4, L5, L6, and L7). Region 1 was defined as the portion of Oahe Reservoir from the dam (RM1072.5) to RM 1084.9 and was represented by station L1. Region 2 was defined as the portion of reservoir from RM1084.9 to RM1103.6 and was represented by station L2. Region 3 was defined as the reach of the reservoir from RM1103.6 to RM1122.2 and was represented by station L3. Region 4 was defined as the portion of the reservoir from RM1122.2 to RM1147.1 and was represented by station L4. Region 5 was defined as the reach of the reservoir from RM1147.1 to 1165.7 and was represented by station L5. Region 6 was defined as the portion of the reservoir RM1165.7 to RM 1184.4 and was represented by station L6. Region 7 was defined as the reach of the reservoir upstream from RM 1184.4 and was represented by station L7. Table 4.3 gives an elevation-volume relationship that was established for each of the seven regions of the reservoir. The elevation-volume relationship was based on the bathymetry grids developed by the Corps in an earlier application of the CE-QUAL-W2 Hydrodynamic and Water Quality Model to Oahe Reservoir (Cole et. al., 1994).

Table 4.3. Estimation of "regional" volumes (acre-feet) in Oahe Reservoir based on pool elevations.

Reservoir Elevation (ft-msl)	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Sum Volume*	Corps Volume**
1610	2,421,533	3,211,081	4,067,639	2,592,578	1,435,071	1,864,855	4,111,139	19,703,896	19,630,460
1605	2,324,234	3,056,732	3,803,414	2,433,436	1,330,776	1,691,116	3,570,247	18,209,955	18,068,750
1600	2,226,736	2,903,073	3,542,326	2,275,157	1,228,032	1,521,997	3,058,954	16,756,276	16,618,390
1595	2,130,417	2,752,251	3,290,350	2,119,963	1,128,268	1,359,864	2,575,600	15,356,712	15,265,460
1590	2,035,834	2,605,374	3,050,181	1,969,214	1,032,386	1,206,560	2,126,345	14,025,894	14,002,600
1585	1,942,338	2,463,228	2,821,818	1,825,117	942,230	1,067,964	1,763,461	12,826,157	12,816,650
1580	1,851,964	2,326,572	2,607,543	1,687,202	856,704	938,351	1,448,905	11,717,241	11,711,030
1575	1,763,790	2,193,898	2,401,091	1,553,896	774,789	815,978	1,165,435	10,668,877	10,686,750
1570	1,677,762	2,065,104	2,202,128	1,425,226	696,592	700,862	909,754	9,677,428	9,737,896
1565	1,594,614	1,941,329	2,015,729	1,302,851	623,515	594,814	687,383	8,760,235	8,859,708
1560	1,514,540	1,822,706	1,842,676	1,186,178	554,399	495,867	528,688	7,945,053	8,049,792
1555	1,436,453	1,707,662	1,675,786	1,073,551	488,196	402,561	397,571	7,181,779	7,308,917
1550	1,359,893	1,595,605	1,515,548	964,766	424,810	320,709	288,640	6,469,970	6,622,830
1545	1,284,271	1,485,846	1,365,569	860,010	364,434	263,509	202,950	5,826,589	5,976,361
1540	1,211,022	1,380,192	1,222,742	760,497	307,390	219,156	139,452	5,240,451	5,373,030
1535	1,138,470	1,276,208	1,085,857	663,954	256,698	178,083	90,723	4,689,992	4,811,149
1530	1,067,386	1,174,942	957,047	571,930	213,226	140,161	55,208	4,179,901	4,291,179
1525	998,716	1,077,622	838,255	486,073	177,103	105,731	30,381	3,713,881	3,816,092
1520	931,330	982,807	727,708	404,634	148,411	74,765	13,085	3,282,739	3,376,665
1515	864,479	889,639	620,922	336,858	120,453	47,619	3,601	2,883,570	2,963,104
1510	798,973	799,257	519,513	280,211	93,944	24,971	0	2,516,869	2,580,093
1505	735,266	712,233	425,413	231,765	69,349	7,462	0	2,181,489	2,230,168
1500	671,783	626,381	353,633	191,704	46,519	1,444	0	1,891,465	1,909,988
1495	610,507	544,724	295,430	154,099	27,452	0	0	1,632,211	1,616,237
1490	550,829	470,601	243,279	118,749	13,358	0	0	1,396,816	1,351,384
1485	492,353	405,799	194,182	85,601	4,714	0	0	1,182,648	1,118,595
1480	434,288	351,387	150,997	54,776	719	0	0	992,167	912,471
1475	378,785	299,992	111,580	30,508	0	0	0	820,865	727,718
1470	324,743	250,423	76,129	14,170	0	0	0	665,464	567,191
1465	271,689	202,173	44,567	5,250	0	0	0	523,679	433,732
1460	219,052	154,627	16,426	563	0	0	0	390,666	322,090
1455	186,621	117,189	4,350	0	0	0	0	308,160	227,402
1450	157,306	82,586	0	0	0	0	0	239,893	151,352
1445	128,622	51,905	0	0	0	0	0	180,527	95,538
1440	100,926	29,127	0	0	0	0	0	130,052	55,360
1435	75,332	19,363	0	0	0	0	0	94,695	27,137
1430	52,107	12,009	0	0	0	0	0	64,116	9,708
1425	13,311	1,693	0	0	0	0	0	15,004	1,640
1420	13,264	1,687	0	0	0	0	0	14,951	73
1415	3,061	389	0	0	0	0	0	3,450	0
1410	0	0	0	0	0	0	0	0	0

* Total reservoir volume based on summing estimated regional reservoir volumes.
** Total reservoir volume from Corps Area-Capacity Tables based on 1989 survey.

Measured water temperature and dissolved oxygen concentration depth-profiles at each of the seven reservoir sites were used to estimate the volume of coldwater habitat in each the seven defined reservoir regions represented by the appropriate station. Water temperature and dissolved oxygen concentration depth-profiles measured at monitoring stations L1 through L7 were compared to Table 4.3, and linear interpolation was used to estimate the volume of water in that reservoir region that met the defined coldwater habitat criteria defined in Table 4.2.

5 OAHE RESERVOIR WATER QUALITY CONDITIONS

5.1 EXISTING WATER QUALITY CONDITIONS – 2005 THROUGH 2007

5.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Tables 5.1 through 5.7 summarize the water quality conditions that were monitored at the seven monitoring sites in Oahe Reservoir during the 3-year period of 2005 through 2007. A review of these results indicated possible water quality concerns regarding water temperature, dissolved oxygen, and pH for the support of the designated coldwater permanent fish life propagation use. The monitoring results for water temperature, dissolved oxygen, and pH summarized in Table 5.1 through 5.7 represent 1-meter incremental measurements taken from the reservoir surface to the bottom.

Late spring and summer water temperatures monitored in Oahe Reservoir commonly exceeded the 65°F (18.3°C) criterion set by the State of South Dakota for the protection of the designated use of coldwater permanent fish life propagation. The number of measurements exceeding the temperature criterion at the seven sites over the 3-year period ranged from 22% near Oahe Dam (Table 5.1) to 93% in the Mobridge area (Table 5.7). During the summer, water temperatures in the epilimnion of Oahe Reservoir typically exceed the criterion, with the criterion only being met in the hypolimnion. The upper limit of the hypolimnion is defined by the depth of the thermocline, which becomes established in Oahe Reservoir at a depth of about 20 meters during mid-summer. Therefore, the hypolimnetic volume of Oahe Reservoir attenuates as the reservoir becomes shallower in its upper reaches, and the temperature criterion for coldwater permanent fish life propagation is exceeded with greater frequency. The water temperature criterion defined by the State for the protection of coldwater marginal fish life protection, ≤ 75°F (23.9°C), was met at a much higher frequency in Oahe Reservoir (Tables 5.1 - 5.7).

Late spring and summer dissolved oxygen concentrations monitored in Oahe Reservoir were commonly below the 7 mg/l criterion, and occasionally below the 6 mg/l criterion set by the State of South Dakota for the protection of the designated use of coldwater permanent fish life propagation. The number of measurements below the 7 mg/l criterion at the seven sites over the 3-year period ranged from 7% near Oahe Dam (Table 5.1) to 26% in the Sutton Bay area (Table 5.4). While measurements below the 6 mg/l criterion ranged from none in the near-dam area (Tables 5.1 and 5.2) to 16% in the Sutton Bay area (Table 5.4). The lower dissolved oxygen levels monitored in Oahe Reservoir occurred near the reservoir bottom, and typically were associated with periods of thermal stratification during mid to late-summer. The 7 mg/l dissolved oxygen criterion only applies to spawning areas during spawning seasons. The only coldwater species that spawns in Oahe Reservoir is the threadfin shad. Threadfin shad spawn in shallow, shoreline areas during the spring. Dissolved oxygen levels in these areas during the spring meet the 7 mg/l dissolved oxygen criterion. The extent of the volume of Oahe Reservoir that does not meet the 6 mg/l dissolved oxygen criterion is not believed to represent a significant water quality concern at this time.

Late spring and summer pH levels monitored in Oahe Reservoir commonly exceeded the upper 8.6 SU criterion set by the State of South Dakota for the protection of coldwater permanent fish life propagation. The number of measurements exceeding the upper pH criterion at the seven sites over the 3-year period ranged from none in the middle of the reservoir (Table 5.4 and 5.5) to 20% in the Cheyenne River area (Table 5.3). The highest pH value measured was only 9.0, and the frequency and magnitude of the pH measurements exceeding the 8.6 criterion are not believed to represent a significant water quality concern at this time.

Table 5.1. Summary of monthly (May through September) water quality conditions monitored in Oahe Reservoir near Oahe Dam (Site OAHLK1073A –L1) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean*	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	15	1577.1	1576.9	1570.9	1583.2	-----	-----	-----
Water Temperature (C)	0.1	660	13.7	12.5	6.1	24.9	18.3[1], 23 9[1]	147, 9	22%, 1%
Dissolved Oxygen (mg/l)	0.1	660	8.9	8.4	6.0	12.2	6.0[2], 7.0[2]	0, 46	0%, 7%
Dissolved Oxygen (% Sat.)	0.1	660	88.7	91.7	8.4	108.7	----	-----	-----
Specific Conductance (umho/cm)	1	659	675	697	534	765	-----	-----	-----
pH (S.U.)	0.1	660	8.3	8.3	7.5	9.0	6.6[3], 8.6[3]	0, 101	0%, 15%
Turbidity (NTUs)	0.1	659	6.0	2.2	n.d.	47.9	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	618	367	366	276	465	-----	-----	-----
Secchi Depth (in.)	1	15	159	144	70	252	-----	-----	-----
Alkalinity, Total (mg/l)	7	32	169	169	140	190	-----	-----	-----
Ammonia, Total (mg/l)	0.01	32	-----	0.03	n.d.	0.11	3.15 [4,5], 1.44 [4,6]	0	0%
Carbon, Total Organic (mg/l)	0.05	30	0.1	3.1	1.6	3.5	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	21	8	8	n.d.	20	-----	-----	-----
Chloride (mg/l)	1	22	9	9	9	11	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	658	-----	1	n.d.	5	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	14	-----	n.d.	n.d.	11	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	28	462	460	410	510	1,750[7]	0	0%
Iron, Total (ug/l)	40	19	111	100	n.d.	262	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	32	0.3	0.3	n.d.	0.6	-----	-----	-----
Manganese, Total (ug/l)	1	21	25	20	3	75	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	32	-----	n.d.	n.d.	0.19	10[7]	0	0%
Phosphorus, Dissolved (mg/l)	0.01	30	-----	0.02	n.d.	0.08	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	32	0.05	0.04	n.d.	0 20	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.01	32	-----	n.d.	n.d.	0.05	-----	-----	-----
Sulfate (mg/l)	0.1	28	200	200	163	220	875[7]	0	0%
Suspended Solids, Total (mg/l)	4	32	-----	n.d.	n.d.	9	53[5], 30[6]	0	0%
Microcystins, Total (ug/l)	0.2	14	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.

* Results are a combination of all sampling depths.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).

*** [1] The State temperature criterion for protection of coldwater permanent fish life propagation, which is a designated use of Oahe Reservoir, is 18.3 C. For reference, the defined State criterion for protection of coldwater marginal fish life propagation is 23.9 C.

[2] Minimum dissolved oxygen criteria for the protection of coldwater permanent fish life propagation. The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.

[3] The pH criteria of 6.6 and 8.6 are, respectively, minimum and maximum criteria.

[4] Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.

[5] Acute criterion for aquatic life.

[6] Chronic criterion for aquatic life.

[7] Daily maximum criterion for domestic water supply.

Table 5.2. Summary of monthly (June through September) water quality conditions monitored in Oahe Reservoir near Cow Creek (site OAHLK1090DW – L2) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	12	1577.1	1576.8	1570.9	1583.2	-----	-----	-----
Water Temperature (C)	0.1	486	15.6	15.4	8.1	27.1	18.3[1], 23.9[1]	150, 15	31%, 3%
Dissolved Oxygen (mg/l)	0.1	486	8.1	8.1	6.1	10.3	6.0[2], 7.0[2]	0, 78	0%, 16%
Dissolved Oxygen (% Sat.)	0.1	486	84.9	86.8	59.2	102.8	-----	-----	-----
Specific Conductance (umho/cm)	1	486	676	694	536	770	-----	-----	-----
pH (S.U.)	0.1	486	8.3	8.4	7.5	8.9	6.6[3], 8.6[3]	0, 83	0%, 17%
Turbidity (NTUs)	0.1	484	5.8	2.1	n.d.	79.9	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	486	359	553	274	468	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	486	-----	1	n.d.	39	-----	-----	-----
Secchi Depth (in)	1	12	139	137	60	228	-----	-----	-----

* Results are a combination of all sampling depths.

** The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** [1] The State temperature criterion for protection of coldwater permanent fish life propagation, which is a designated use of Oahe Reservoir, is 18.3 C. For reference, the defined State criterion for protection of coldwater marginal fish life propagation is 23.9 C.

[2] Minimum dissolved oxygen criteria for the protection of coldwater permanent fish life propagation. The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.

[3] The pH criteria of 6.6 and 8.6 are, respectively, minimum and maximum criteria.

Table 5.3. Summary of monthly (May through September) water quality conditions monitored in Oahe Reservoir near the confluence of the Cheyenne River (Site OAHLK1110DW – L3) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	12	1577.1	1576.9	1570.9	1583.2	-----	-----	-----
Water Temperature (C)	0.1	373	17.9	17.8	9.7	25.2	18.3[1], 23.9[1]	175, 28	47%, 8%
Dissolved Oxygen (mg/l)	0.1	373	7.7	8.0	3.4	9.3	6.0[2], 7.0[2]	37, 70	10%, 19%
Dissolved Oxygen (% Sat.)	0.1	373	85.5	89.9	33.9	104.7	----	-----	-----
Specific Conductance (umho/cm)	1	373	669	682	536	782	-----	-----	-----
pH (S.U.)	0.1	373	8.3	8.4	7.5	8.8	6.6[3], 8.6[3]	0, 76	0%, 20%
Turbidity (NTUs)	0.1	368	5.7	3.0	0.1	37.3	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	373	355	334	245	459	-----	-----	-----
Secchi Depth (in.)	1	12	115	114	60	192	-----	-----	-----
Alkalinity, Total (mg/l)	7	27	165	165	140	180	-----	-----	-----
Ammonia, Total (mg/l)	0.01	27	-----	n.d.	n.d.	0.12	2.59[4,5], 0.98[4,6]	0	0%
Carbon, Total Organic (mg/l)	0.05	25	3.1	3.1	1.3	4.6	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	16	12	11	2	19	-----	-----	-----
Chloride (mg/l)	1	16	10	10	8	12	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	370	-----	1	n.d.	6	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	12	-----	n.d.	n.d.	3	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	26	459	453	414	556	1,750[7]	0	0%
Iron, Total (ug/l)	40	20	158	150	n.d.	394	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	27	0.3	0.3	n.d.	0.7	-----	-----	-----
Manganese, Total (ug/l)	1	20	36	23	n.d.	129	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	26	-----	n.d.	n.d.	0.20	10[7]	0	0%
Phosphorus, Dissolved (mg/l)	0.01	27	-----	0.01	n.d.	0.08	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	27	0.06	0.04	n.d.	0 25	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.01	27	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/l)	0.1	25	194	200	161	220	875[7]	0	0%
Suspended Solids, Total (mg/l)	4	26	-----	n.d.	n.d.	13	53[5], 30[6]	0	0%
Microcystins, Total (ug/l)	0.2	12	-----	n.d.	n.d.	0.23	-----	-----	-----

n.d. = Not detected.
* Results are a combination of all sampling depths.
** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).
*** (1) The State temperature criterion for protection of coldwater permanent fish life propagation, which is a designated use of Oahe Reservoir, is 18.3 C. For reference, the defined State criterion for protection of coldwater marginal fish life propagation is 23.9 C.
(2) Minimum dissolved oxygen criteria for the protection of coldwater permanent fish life propagation. The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
(3) The pH criteria of 6.6 and 8.6 are, respectively, minimum and maximum criteria.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(5) Acute criterion for aquatic life.
(6) Chronic criterion for aquatic life.
(7) Daily maximum criterion for domestic water supply.

Table 5.4. Summary of monthly (June through September) water quality conditions monitored in Oahe Reservoir near Sutton Bay (site OAHLK1135DW – L4) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	11	1577.1	1576.9	1570.9	1583.2	-----	-----	-----
Water Temperature (C)	0.1	317	18.7	18.6	10.5	25.4	18.3[1], 23.9[1]	163, 13	51%, 4%
Dissolved Oxygen (mg/l)	0.1	317	7.4	7.8	3.5	9.7	6.0[2], 7.0[2]	50, 82	16%, 26%
Dissolved Oxygen (% Sat.)	0.1	316	83.1	88.5	35.9	107.3	-----	-----	-----
Specific Conductance (umho/cm)	1	317	654	659	532	732	-----	-----	-----
pH (S.U.)	0.1	317	8.3	8.3	7.6	8.6	6.6[3], 8.6[3]	0	0%
Turbidity (NTUs)	0.1	315	6.2	3.7	0.6	34.1	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	316	378	376	296	469	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	313	-----	1	n.d.	6	-----	-----	-----
Secchi Depth (in)	1	11	90	100	40	122	-----	-----	-----

* Results are a combination of all sampling depths.
** The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).
*** (1) The State temperature criterion for protection of coldwater permanent fish life propagation, which is a designated use of Oahe Reservoir, is 18.3 C. For reference, the defined State criterion for protection of coldwater marginal fish life propagation is 23.9 C.
(2) Minimum dissolved oxygen criteria for the protection of coldwater permanent fish life propagation. The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
(3) The pH criteria of 6.6 and 8.6 are, respectively, minimum and maximum criteria.

Table 5.5. Summary of monthly (June through September) water quality conditions monitored in Oahe Reservoir near Whitlocks Bay (Site OAHLK1153DW – L5) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	12	1577.1	1576.9	1571.1	1583.2	-----	-----	-----
Water Temperature (C)	0.1	291	19.6	20.2	11.5	25.7	18.3(1), 23 9(1)	183, 23	63%, 8%
Dissolved Oxygen (mg/l)	0.1	291	7.3	7.7	2.5	9.3	6.0(2), 7.0(2)	42, 65	14%, 22%
Dissolved Oxygen (% Sat.)	0.1	291	83.1	88.7	27.7	104.8	----	-----	-----
Specific Conductance (umho/cm)	1	290	645	656	539	741	-----	-----	-----
pH (S.U.)	0.1	291	8.3	8.4	7.5	8.6	6.6(3), 8.6(3)	0	0%
Turbidity (NTUs)	0.1	290	5.7	4.6	1.1	23.0	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	291	391	395	297	492	-----	-----	-----
Secchi Depth (in.)	1	12	78	79	41	120	-----	-----	-----
Alkalinity, Total (mg/l)	7	26	164	168	140	180	-----	-----	-----
Ammonia, Total (mg/l)	0.01	26	-----	0.03	n.d.	0.31	2.59 (4,5), 0.85 (4,6)	0	0%
Carbon, Total Organic (mg/l)	0.05	24	3.2	3.2	1.6	5.0	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	16	12	11	n.d.	23	-----	-----	-----
Chloride (mg/l)	1	16	9	9	8	10	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	289	-----	1	n.d.	26	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	12	4	4	n.d.	7	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	26	450	439	420	532	1,750(7)	0	0%
Iron, Total (ug/l)	40	20	218	198	40	589	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	26	0.4	0.4	0.2	0.8	-----	-----	-----
Manganese, Total (ug/l)	1	20	120	67	10	532	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	26	-----	0.04	n.d.	0.30	10(7)	0	0%
Phosphorus, Dissolved (mg/l)	0.01	26	-----	0.03	n.d.	0.16	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	26	0.07	0.06	n.d.	0 23	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.01	26	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/l)	0.1	24	181	190	152	200	875(7)	0	0%
Suspended Solids, Total (mg/l)	4	26	-----	n.d.	n.d.	14	53(5), 30(6)	0	0%
Microcystins, Total (ug/l)	0.2	12	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.
* Results are a combination of all sampling depths.
** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e , log conversion of logarithmic pH values was not done to calculate mean).
*** (1) The State temperature criterion for protection of coldwater permanent fish life propagation, which is a designated use of Oahe Reservoir, is 18.3 C. For reference, the defined State criterion for protection of coldwater marginal fish life propagation is 23.9 C.
(2) Minimum dissolved oxygen criteria for the protection of coldwater permanent fish life propagation. The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
(3) The pH criteria of 6.6 and 8.6 are, respectively, minimum and maximum criteria.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(5) Acute criterion for aquatic life.
(6) Chronic criterion for aquatic life.
(7) Daily maximum criterion for domestic water supply.

Table 5.6. Summary of monthly (June through September) water quality conditions monitored in Oahe Reservoir near Swan Creek (site OAHLK1176DW – L6) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	12	1577.1	1576.9	1571.1	1583.2	-----	-----	-----
Water Temperature (C)	0.1	213	20.9	20.4	15.5	25.3	18.3(1), 23.9(1)	169, 40	79%, 19%
Dissolved Oxygen (mg/l)	0.1	213	7.6	7.8	2.7	9.7	6.0(2), 7.0(2)	15, 34	7%, 16%
Dissolved Oxygen (% Sat.)	0.1	213	88.7	90.2	31.4	110.7	-----	-----	-----
Specific Conductance (umho/cm)	1	213	649	659	529	763	-----	-----	-----
pH (S.U.)	0.1	213	8.4	8.4	7.8	8.7	6.6(3), 8.6(3)	0, 14	0%, 7%
Turbidity (NTUs)	0.1	211	6.2	4.7	1.5	26.4	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	213	402	411	294	477	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	212	2	2	n.d.	11	-----	-----	-----
Secchi Depth (in)	1	12	59	55	37	92	-----	-----	-----

* Results are a combination of all sampling depths.
** The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).
*** (1) The State temperature criterion for protection of coldwater permanent fish life propagation, which is a designated use of Oahe Reservoir, is 18.3 C. For reference, the defined State criterion for protection of coldwater marginal fish life propagation is 23.9 C.
(2) Minimum dissolved oxygen criteria for the protection of coldwater permanent fish life propagation. The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
(3) The pH criteria of 6.6 and 8.6 are, respectively, minimum and maximum criteria.

Table 5.7. Summary of monthly (June through September) water quality conditions monitored in Oahe Reservoir near Mobridge, South Dakota (Site OAHLK1196DW – L7) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	12	1577.1	1576.9	1571.1	1583 2	-----	-----	-----
Water Temperature (C)	0.1	156	21 3	22.2	15.3	25.1	18.3(1), 23.9(1)	145, 45	93%, 29%
Dissolved Oxygen (mg/l)	0.1	156	7.6	7.8	5.1	8.6	6.0(2), 7.0(2)	5, 23	3%, 15%
Dissolved Oxygen (% Sat.)	0.1	156	89.7	90.1	63.7	98 1	----	-----	-----
Specific Conductance (umho/cm)	1	156	645	651	530	749	-----	-----	-----
pH (S.U.)	0.1	156	8.4	8.4	8.2	8.7	6.6(3), 8.6(3)	0, 20	0%, 13%
Turbidity (NTUs)	0.1	154	13.6	13.1	4.2	31.6	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	156	410	411	296	516	-----	-----	-----
Secchi Depth (in.)	1	12	32	26	17	65	-----	-----	-----
Alkalinity, Total (mg/l)	7	24	161	165	98	180	-----	-----	-----
Ammonia, Total (mg/l)	0.01	24	-----	0.04	n.d.	0.33	2.59 (4,5), 0.75 (4,6)	0	0%
Carbon, Total Organic (mg/l)	0.05	21	3 3	3.2	2.6	4.4	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	16	13	12	9	22	-----	-----	-----
Chloride (mg/l)	1	16	9	9	8	10	-----	-----	-----
Chlorophyll *a* (ug/l) – Field Probe	1	155	5	3	1	17	-----	-----	-----
Chlorophyll *a* (ug/l) – Lab Determined	1	11	6	5	1	15	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	24	457	449	410	560	1,750(7)	0	0%
Iron, Total (ug/l)	40	20	344	330	100	699	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	24	0.4	0.4	n.d.	0.8	-----	-----	-----
Manganese, Total (ug/l)	1	20	49	47	20	110	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	24	-----	n.d.	n.d.	0.11	10(7)	0	0%
Phosphorus, Dissolved (mg/l)	0.01	24	-----	0.02	n.d.	0.09	-----	-----	-----
Phosphorus, Total (mg/l)	0.01	24	0.05	0.05	n.d.	0.15	-----	-----	-----
Phosphorus-Ortho, Dissolved (mg/l)	0.01	24	-----	n.d.	n.d.	0.04	-----	-----	-----
Sulfate (mg/l)	0.1	22	176	190	142	200	875(7)	0	0%
Suspended Solids, Total (mg/l)	4	24	-----	10	n.d.	18	53(5), 30(6)	0	0%
Microcystins, Total (ug/l)	0.2	12	-----	n.d.	n.d.	n.d.	-----	-----	-----

n.d. = Not detected.
* Results are a combination of all sampling depths.
** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).
*** (1) The State temperature criterion for protection of coldwater permanent fish life propagation, which is a designated use of Oahe Reservoir, is 18.3 C. For reference, the defined State criterion for protection of coldwater marginal fish life propagation is 23.9 C.
(2) Minimum dissolved oxygen criteria for the protection of coldwater permanent fish life propagation. The 7.0 mg/l criterion applies to spawning areas during spawning season, and the 6.0 mg/l criterion applies otherwise.
(3) The pH criteria of 6.6 and 8.6 are, respectively, minimum and maximum criteria.
(4) Total ammonia criteria pH and temperature dependent. Criteria listed are for median pH and temperature values.
(5) Acute criterion for aquatic life.
(6) Chronic criterion for aquatic life.
(7) Daily maximum criterion for domestic water supply.

5.1.2 WATER TEMPERATURE

5.1.2.1 Annual Temperature Regime

The water temperature regime of Oahe Reservoir can be described by an annual cycle consisting of eight thermal periods: 1) winter ice cover, 2) spring turnover, 3) spring isothermal conditions, 4) late-spring/early-summer warming, 5) mid-summer maximum thermal stratification, 6) late-summer/early-fall cooling, 7) fall turnover, and 8) fall isothermal conditions leading to winter ice cover. During the winter ice-cover period, Oahe Reservoir will be inversely stratified from the surface to the bottom as the more dense water (i.e., 4°C) settles to the bottom. When the ice cover melts in the spring, the reservoir will become isothermal at about 4°C, and complete mixing of the reservoir volume will occur as spring turnover takes place. As the reservoir gradually warms in the spring, isothermal conditions (>4°C) will occur as long as sufficient energy is present to completely mix the reservoir water column. As the reservoir continues to warm in late spring and early summer, thermal stratification will occur, and the hypolimnion will become established. At some point in mid-summer, the reservoir will reach maximum thermal stratification (i.e., maximum temperature difference between water at the reservoir surface and bottom), and a distinct thermocline will be present. As the reservoir begins to cool in late summer, the epilimnion will expand downward, pushing the thermocline deeper, and the hypolimnetic volume of colder water will decrease. The reservoir will continue to cool until it becomes isothermal and mixing occurs through the entire water column and fall turnover occurs. As the reservoir continues to cool, temperatures will remain relatively isothermal until it cools to 4°C. Ice cover will then be established, and the annual thermal cycle of Oahe Reservoir will be completed.

5.1.2.2 Spatial Variation

Monthly (i.e., June, July, August, and September) longitudinal contour plots along Oahe Reservoir were prepared from the depth-profile water temperature measurements taken at the reservoir monitoring sites during the 3-year period 2005 through 2007 (Plates 1 through 12). As seen in Plates 1 through 12, temperatures in Oahe Reservoir vary longitudinally from the dam to the reservoir's upper reaches and vertically from the reservoir surface to the bottom. The near-surface water in the upper reaches of the reservoir warms up sooner in the spring than the near-surface water near the dam (Plates 1, 5, and 9). By mid-summer a strong thermocline becomes established in the lower reaches of the reservoir, and the near-surface waters of the entire reservoir above the thermocline are a fairly uniform temperature (Plates 2, 3, 6, 7, 10, and 11). As the near-surface waters of the reservoir cool in the late summer, the thermocline is pushed deeper and the wind-mixed upper waters are fairly uniform in temperature (Plates 4, 8, and 12). The vertical variation in temperature is most prevalent in the deeper area of the reservoir towards the dam where a strong thermocline becomes established during the summer. The shallower upper reaches of Oahe Reservoir do not exhibit much vertical variation of temperature during mid to late summer as wind action allows for complete mixing of the water column.

5.1.2.3 Summer Thermal Stratification

Oahe Reservoir exhibited significant thermal stratification during the summer of all 3 years (Plates 2, 3, 6, 7, 10, and 11). During maximum stratification in mid-summer, the thermocline in Oahe Reservoir in 2005, 2006, and 2007 was at a depth of about 20 meters (65 feet). The depth of the thermocline defines the upper limit of the hypolimnion. Where the corresponding elevation of the thermocline intersects the reservoir bottom defines the longitudinal boundary of the hypolimnion in the upper reaches of Oahe Reservoir. During 2005 through 2007, the longitudinal boundary of the hypolimnion was around River Mile 1180. Taking the slope of the reservoir bottom to be about 0.85 feet/mile along the old Missouri River channel, every foot of elevation increase in the pool elevation would extend the boundary of the hypolimnion about 1.2 miles up the reservoir.

5.1.3 DISSOLVED OXYGEN

5.1.3.1 Spatial Variation

Monthly (i.e., June, July, August, and September) longitudinal contour plots along Oahe Reservoir were prepared from the depth-profile dissolved oxygen measurements taken at reservoir monitoring sites L1, L2, L3, L4, L5, L6, and L7 during the 3-year period 2005 through 2007 (Plates 13 through 24). As seen in Plates 13 through 24, dissolved oxygen concentrations in Oahe Reservoir vary longitudinally from the dam to reservoir's upper reaches, and vertically from the reservoir surface to the bottom. An area of low dissolved oxygen (<5 mg/l) was first measured in July near the reservoir bottom in the middle reaches of the reservoir near the upstream extent of the hypolimnion (i.e., RM1180) (Plates 14, 18, and 22). As the summer progressed, the area of low dissolved oxygen expanded downstream towards the dam along the reservoir bottom (Plates 15, 16, 19, 23, and 24). The farthest downstream the measured area of low dissolved oxygen progressed was to about 47 miles upstream of Oahe Dam near RM 1120 in September 2007 (Plate 24). The area of low dissolved oxygen remained near the bottom in the middle region of Oahe reservoir through fall turnover (Plates 16, 20, and 24). Near-bottom dissolved oxygen concentrations in the area immediately upstream of the dam remained above 6 mg/l throughout the summers of all 3 years of the monitored period 2005 through 2007. The earlier occurrence of low dissolved oxygen concentrations in the near-bottom water of the middle reaches of Oahe Reservoir is attributed to the increased allochthonous organic loading in the transition zone of the reservoir and the lesser hypolimnetic volume available for assimilation of the oxygen demand. As this material decomposes, an area of water with low dissolved oxygen levels accumulates near the bottom in this region of the reservoir. Decomposition of autochthonous organic matter also occurs in the lacustrine zone and results in dissolved oxygen degradation as the summer progresses, although at a slower rate than what occurs in the transition zone. The recovery of near-bottom dissolved oxygen concentrations to saturation levels takes longer in the lacustrine zone nearer the dam because of the time needed for thermal stratification to breakdown and mixing within the water column to occur in the deeper water.

5.1.4 WATER CLARITY

5.1.4.1 Secchi Transparency

Figure 5.1 displays the distribution of the Secchi depth transparencies measured in Oahe Reservoir at the seven reservoir monitoring sites as a box plot (note: the seven monitoring sites are oriented in an upstream to downstream direction along the x-axis). Secchi depth transparency increased in a downstream direction from the upper reaches of the reservoir to near the dam (Figure 5.1). This is attributed to suspended sediment in the inflowing Missouri River settling out in the reservoir as current velocities slow. The surface waters near Oahe Dam are appreciably clearer than the upstream regions of the reservoir.

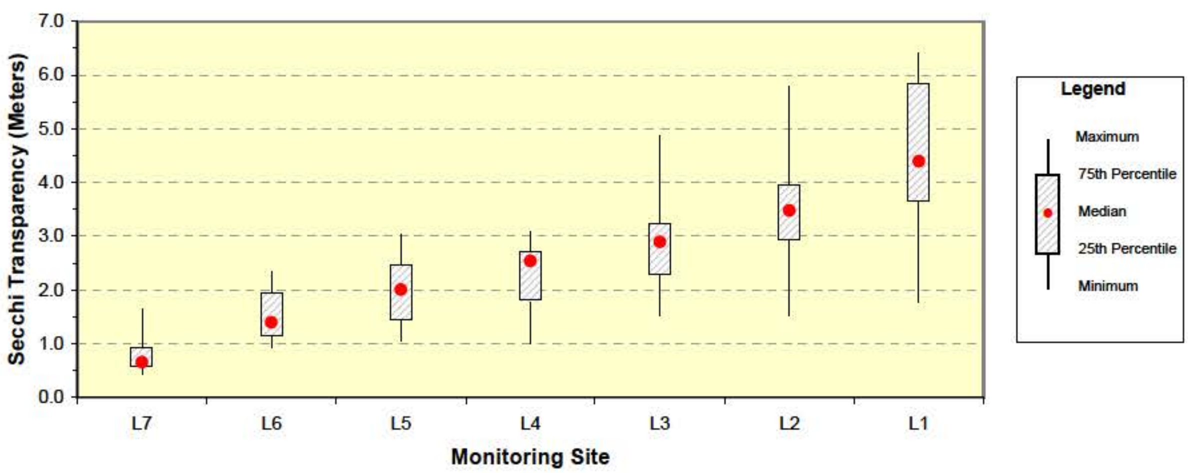

Figure 5.1. Box plot of Secchi transparencies measured in Oahe Reservoir at sites L1 through L7 during the 3-year period 2005 through 2007. (Note: monitoring sites are oriented on the x-axis in an upstream to downstream direction.)

5.1.4.2 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. Monthly (i.e., June, July, August, and September) longitudinal contour plots were prepared from the depth-profile turbidity measurements taken in Oahe Reservoir at sites L1, L2, L3, L4, L5, L6, and L7 during the 3-year period 2005 through 2007 (Plates 25 through 36). As seen in Plates 25 through 36, turbidity levels in Oahe Reservoir vary longitudinally somewhat from the dam to reservoir's upper reaches and vertically somewhat from the reservoir surface to the bottom. Turbidity levels measured in the upper reaches Oahe Reservoir, although somewhat higher than the turbidity levels measured near the dam, are still of a low magnitude. Monitoring during the 3-year period indicates that slight turbidity plumes may occasionally move through the reservoir as interflows (Plates 26, 27, 28, and 34). Given the low chlorophyll *a* concentrations monitored during the 3-year period, (Tables 5.1 through 5.7), turbidity in the reservoir is believed to be due to suspended inorganic material.

The 3-year period 2005 through 2007 was a period of drought in the interior west and runoff into Oahe Reservoir was well below average. The lower runoff is believed to have reduced turbidity levels in Oahe Reservoir during the period.

5.1.5 COMPARISON OF NEAR-SURFACE AND NEAR-BOTTOM WATER QUALITY CONDITIONS

Near-surface and near-bottom water quality conditions monitored in Oahe Reservoir in the near-dam area (i.e., site L1) during May through September over the 3-year period 2005 through 2007 were compared. Near-surface samples were defined to be samples collected within 2 meters of the reservoir surface, and near-bottom samples were defined as samples collected within 2 meters of the reservoir bottom. Box plots were used to display the distribution of the paired near-surface and near-bottom measurements for the following parameters: water temperature, dissolved oxygen, oxidation-reduction potential (ORP), total Kjeldahl nitrogen, total ammonia, nitrate-nitrate nitrogen, total phosphorus, dissolved phosphorus, and total organic carbon (Figure 5.2). Non-overlapping interquartile ranges of the adjacent surface and bottom box plots for a parameter were taken to indicate a significant difference between the measurements. The only parameter that varied significantly between the surface and bottom was water temperature (Figure 5.2). Water temperatures measured near the surface were significantly warmer than those measured near the reservoir bottom.

5.1.6 NUTRIENT CONDITIONS

5.1.6.1 Trophic Status

Trophic State Index (TSI) values for Oahe Reservoir were calculated from the monitoring data collected at sites L1, L3, L5, and L7 during the 3-year period 2005 through 2007 (Table 5.8). The calculated TSI values indicate that downstream region of Oahe Reservoir represented by sites L1 and L3 is in a mesotrophic state, and the upstream region of the reservoir represented by sites L5 and L7 is in a moderately eutrophic to eutrophic state.

Table 5.8. Mean Trophic State Index (TSI) values calculated for Oahe Reservoir at four reservoir monitoring sites based on measured Secchi depth, total phosphorus, and chlorophyll *a* values during the 3-year period 2005 through 2007.

Site	No. of Obs.	Mean – TSI (Secchi Depth)	Mean – TSI (Total Phos.)	Mean – TSI (Chlorophyll)	Mean – TSI (Average)
L1	15	41	51	44	46
L3	12	45	54	43	47
L5	12	51	56	50	52
L7	12	64	55	54	58

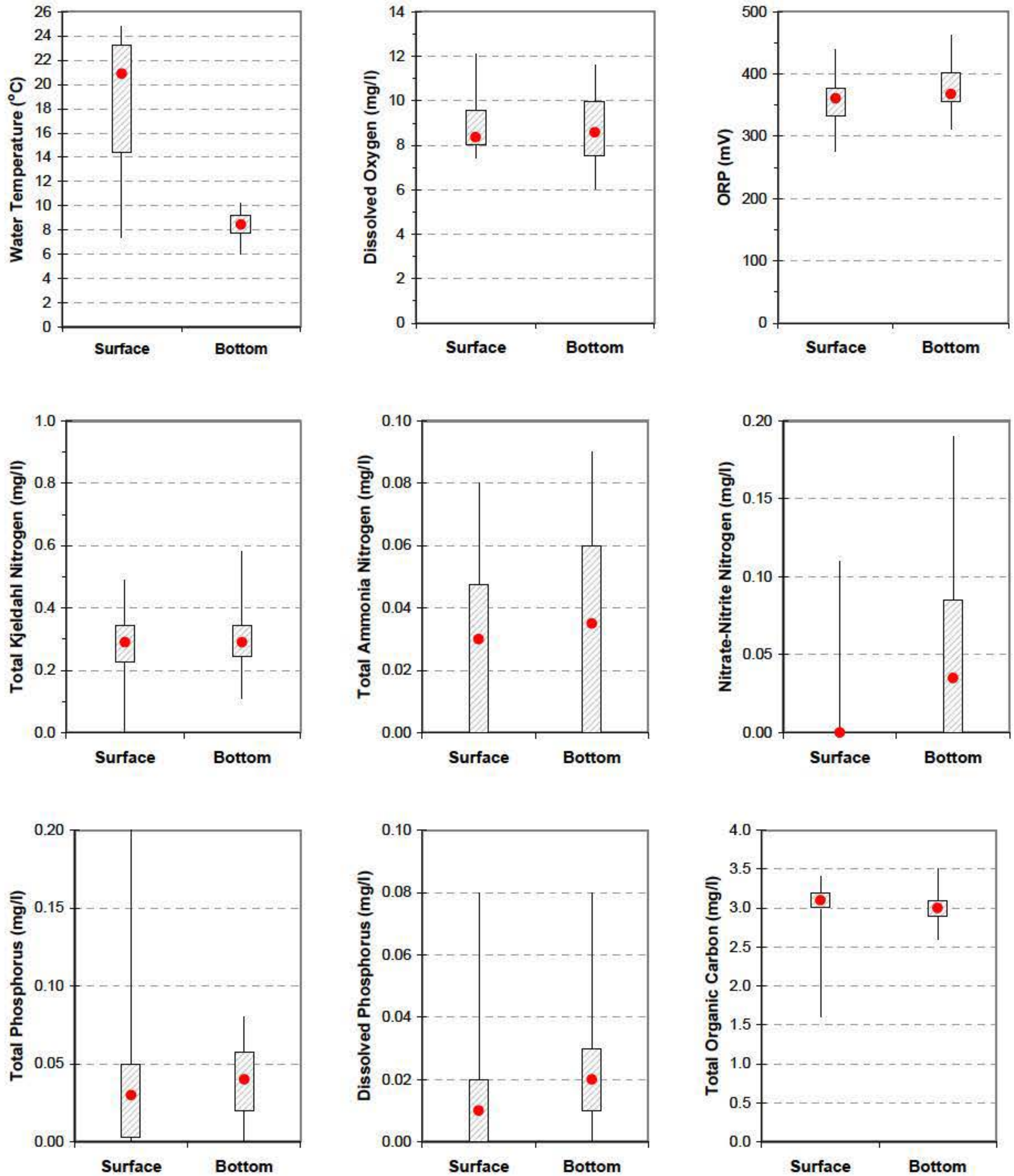

Figure 5.2. Box plots comparing surface and bottom water temperature, dissolved oxygen, oxidation-reduction potential (ORP), total Kjeldahl nitrogen, total ammonia nitrogen, nitrate-nitrite nitrogen, total phosphorus, dissolved phosphorus, and total organic carbon measured monthly (May through September) in Oahe Reservoir at site L1 during the 3-year period 2005 through 2007. (Box plots display minimum, 25th percentile, 75th percentile, and maximum. Median value is indicated by the red dot. Non-overlapping interquartile ranges of the adjacent box plots are taken to indicate a significant difference between surface and bottom measurements.)

5.1.6.2 Missouri River Nutrient Flux Conditions

Nutrient flux rates for the Missouri River were calculated based on water quality samples collected at Bismarck, North Dakota (i.e. site NF1) and estimated instantaneous flow conditions at the time of sample collection (Table 5.9). The maximum nutrient flux rates are attributed to greater nonpoint source nutrient loadings associated with runoff conditions.

Table 5.9. Summary of nutrient flux rates (kg/sec) calculated for the Missouri River at Bismarck, North Dakota during May through September over the 3-year period 2005 through 2007.

Statistic	Total Ammonia N (kg/sec)	Total Kjeldahl N (kg/sec)	Total NO_3-NO_2 N (kg/sec)	Total Phosphorus (kg/sec)	Dissolved Phosphorus (kg/sec)	Total Organic Carbon (kg/sec)
No. of Obs.	15	15	14	15	15	14
Mean*	-----	-----	0.033	0.051	-----	1.411
Median	0.010	0.135	0.033	0.025	0.009	1.513
Minimum	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Maximum	0.049	0.153	0.063	0.103	0.016	2.277

n.d. = non-detectable.

* Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetects, mean is not reported

Note: Statistics of Missouri River flows used for flux calculations were: mean = 17,053 cfs, median = 16,000 cfs, minimum = 11,899 cfs, and maximum = 26,800 cfs.

5.1.7 PHYTOPLANKTON COMMUNITY

Phytoplankton grab samples collected from Oahe Reservoir at sites L1, L3, L5, and L7 during May/June through September over the 3-year period 2005 through 2007 are summarized in Plates 37 through 40. The following seven taxonomic divisions were represented by taxa collected in the phytoplankton samples: Bacillariophyta (Diatoms), Chlorophyta (Green Algae), Chrysophyta (Golden Algae), Cryptophyta (Cryptomonad Algae), Cyanobacteria (Blue-Green Algae), Pyrrophyta (Dinoflagellate Algae), and Euglenophyta (Euglenoid Algae). The general prevalence of these taxonomic divisions in the reservoir, based on taxa occurrence, were Bacillariophyta > Chlorophyta > Cyanobacteria > Cryptophyta > Pyrrophyta > Chrysophyta > Euglenophyta. The diatoms were generally the most abundant algae based on percent composition (Plates 37 - 40). The Shannon-Weaver genera diversity indices calculated for the 50 phytoplankton samples collected at the four sites ranged from 0.55 to 2.53 and averaged 1.69 at site L1, 1.73 at site L3, 1.46 at site L5, and 1.50 at site L7. Dominant phytoplankton species occurring in the 15 samples collected at site L1 included the Bacillariophyta *Fragilaria sp.* (9 occasions), *Asterionella sp.* (6 occasions), *Stephanodiscus sp.* (3 occasions), *Aulacoseira sp.* (1 occasion), *Cyclotella sp.* (1 occasion), *Navicula sp.* (1 occasion), *Synedra sp.* (1 occasion), and *Tabellaria sp.*; Chlorophyta *Cosmarium sp.* (3 occasions), *Chlamydomonas sp.* (1 occasion), and *Golenkinia sp.* (1 occasion); Chrysophyta *Dinobryon sp.* (4 occasions); Cryptophyta *Rhodomonas sp.* (5 occasions); Cyanobacteria *Anabaena sp.* (2 occasions); and Pyrrophyta *Ceratium sp.* (6 occasions) and *Peridinium sp* (one occasion) (Plate 41). The highest value of the cyanobacterial toxin microcystins measured at the four sites L1, L3, L5, and L7 over the 3-year period 2005 through 2007 was 0.23 ug/l at site L3 (Tables 5.1, 5.3, 5.5, and 5.7).

5.2 COLDWATER HABITAT IN OAHE RESERVOIR

5.2.1 ANNUAL OCCURRENCE OF COLDWATER HABITAT

The occurrence of coldwater habitat in Oahe Reservoir is directly dependent on the reservoir's annual thermal regime. Early in the winter ice-cover period, the entire reservoir volume will be supportive of coldwater habitat. As the winter ice-cover period continues, lower dissolved oxygen concentrations may occur near the bottom as organic matter decomposes and reservoir mixing is prevented by ice cover. As dissolved oxygen concentrations in the near-bottom water fall below 6 mg/l, a coldwater permanent fish life propagation use will not be supported. During the spring isothermal period, water temperatures and dissolved oxygen levels in the entire reservoir volume will be supportive of coldwater habitat. During the early-summer reservoir warming period, coldwater habitat will decrease as water temperatures in the epilimnion become non-supportive of the coldwater permanent fish life propagation use. During mid-summer when the reservoir is experiencing maximum thermal stratification, water temperatures will only be supportive of the coldwater permanent fish life propagation use in the hypolimnion. Theoretically, coldwater habitat should remain stable during this period unless degradation of dissolved oxygen concentrations near the reservoir bottom become limiting (i.e., < 6 mg/l). The most critical period for the support of coldwater habitat in Oahe Reservoir is when the reservoir begins to cool in late summer. As the thermocline moves deeper, the volume of the coldwater hypolimnion will continue to decrease while the expanding epilminion may not yet be cold enough to be supportive of the coldwater permanent fish life propagation use. At the same time, hypolimnetic dissolved oxygen concentrations are approaching their maximum degradation and low dissolved oxygen levels are moving upward from the reservoir bottom and potentially pinching off coldwater habitat from below. This situation will continue until the epilimnion cools enough to be supportive of the coldwater permanent fish life propagation use. When fall turnover occurs, dissolved oxygen concentrations at all depths will be near saturation and supportive of the coldwater permanent fish life propagation use.

5.2.2 INTERACTION OF WATER TEMPERATURE AND DISSOLVED OXYGEN IN DETERMINING THE OCCURRENCE OF COLDWATER HABITAT

The occurrence of coldwater habitat is determined by the interaction of water temperature and dissolved oxygen concentrations as they vary with reservoir depth. The interaction of varying water temperature and dissolved oxygen with depth in determining the occurrence of coldwater habitat at sites L1 and L3 are shown, respectively, in Figures 5.3 and 5.4. These figures plot the 18.3°C water temperature and 6 mg/l dissolved oxygen concentration isopleths at stations L1 and L3 for 2005, 2006, and 2007. It is noted that dissolved oxygen concentrations below 6 mg/l were not measured at site L1 during the monitored period. Coldwater habitat supportive of the coldwater permanent fish life propagation use is represented by the area below the 18.3°C temperature isopleth and above the 6 mg/l dissolved oxygen isopleth. As shown in Figures 5.3 and 5.4, the increasing depth of 18.3°C water during the summer, resulted in a decline in the amount of coldwater habitat supportive of the coldwater permanent fish propagation use at sites L1 and L3. Degraded dissolved oxygen conditions moving up from the reservoir bottom at site L3 also reduced the amount of coldwater habitat supportive of the coldwater permanent fish life propagation use in the Cheyenne River area of Oahe Reservoir (Figure 5.4). In all 3 years, water temperature and dissolved oxygen conditions monitored in August indicated that no coldwater habitat was present at site L3 that supported the coldwater permanent fish propagation use. During August degraded dissolved oxygen conditions (i.e., <6 mg/l) had moved up in the water column from the reservoir bottom, such that the depth to water having less than 6 mg/l dissolved oxygen was above the depth where water had a temperature of 18.3° C or less (Figure 5.4).

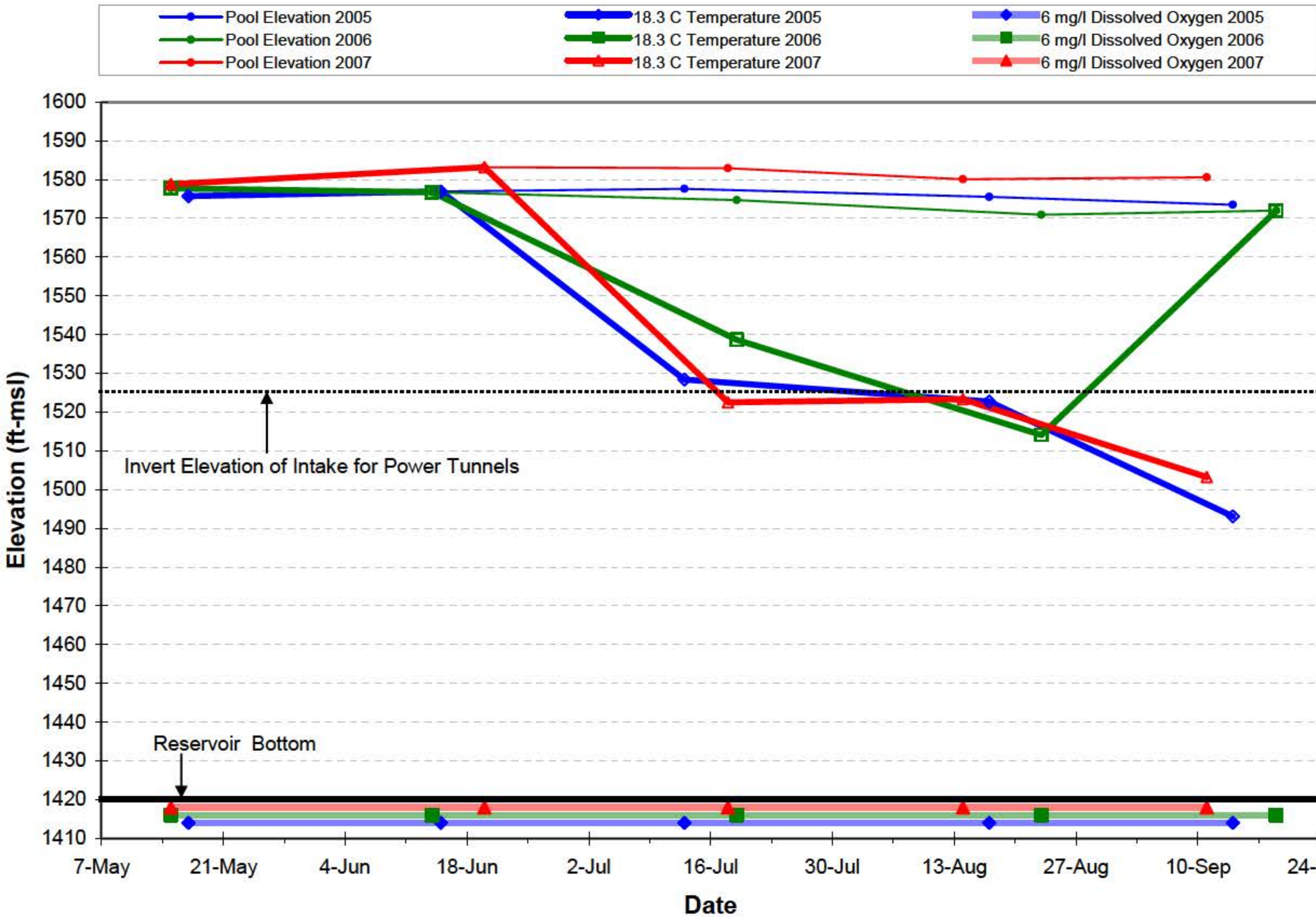

Figure 5.3. Elevations of the reservoir pool, 18.3°C water temperature, and 6 mg/l dissolved oxygen concentration by year for station L1. Coldwater habitat supportive of the coldwater permanent fish life propagation use is represented by the area between the 18.3°C temperature and 6 mg/l dissolved oxygen isopleths.

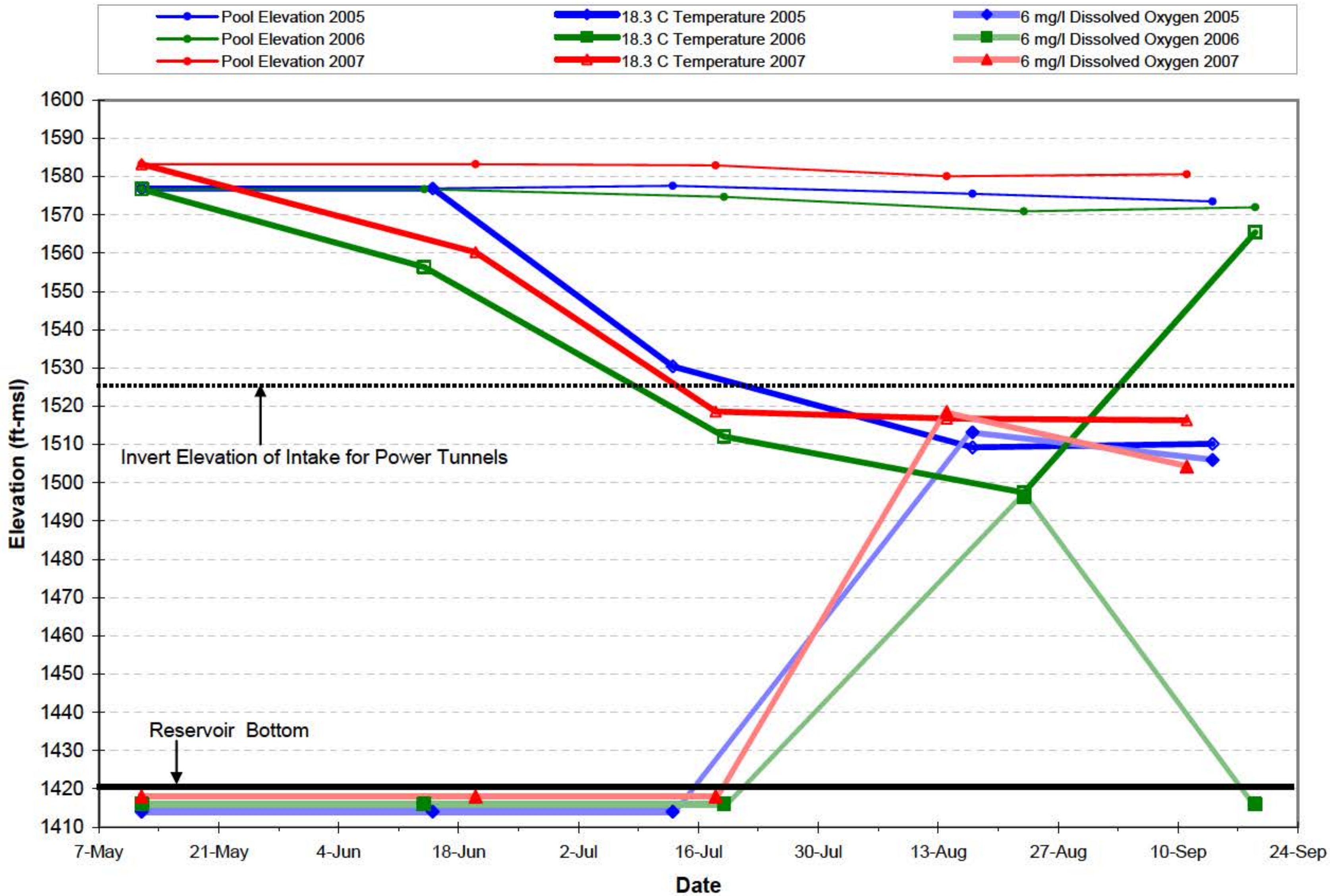

Figure 5.4. Elevations of the reservoir pool, 18.3°C water temperature, and 6 mg/l dissolved oxygen concentration by year for station L3. Coldwater habitat supportive of the coldwater permanent fish life propagation use is represented by the area between the 18.3°C temperature and 6 mg/l dissolved oxygen isopleths.

5.2.3 OCCURRENCE OF COLDWATER HABITAT DURING THE PERIOD 2005 THROUGH 2007

The volumes of coldwater habitat supportive of the permanent and marginal fish life propagation uses estimated to be present in Oahe Reservoir during the months of June through September over the 3-year period of 2005 through 2007 are given in Plates 42 through 53. Figure 5.5 shows the total reservoir volume and the amount of coldwater habitat supportive of the permanent and marginal fish life propagation uses estimated to have been present in Oahe Reservoir during 2005, 2006, and 2007. The volume of coldwater habitat in Oahe Reservoir steadily decreased from June through August of all 3 years (Figure 5.5). Except for 2006, the steady decrease of coldwater habitat continued through the conditions that were monitored in September (Figure 5.5). When Oahe Reservoir was monitored on September 19, 2006, the reservoir had experienced fall turnover which mixed the water column throughout the reservoir (Plates 8 and 20). The mixing of the reservoir during fall turnover resulted in temperature and dissolved oxygen conditions that were largely supportive coldwater permanent fish life propagation throughout Oahe Reservoir on September 19, 2006 (Figure 5.5).

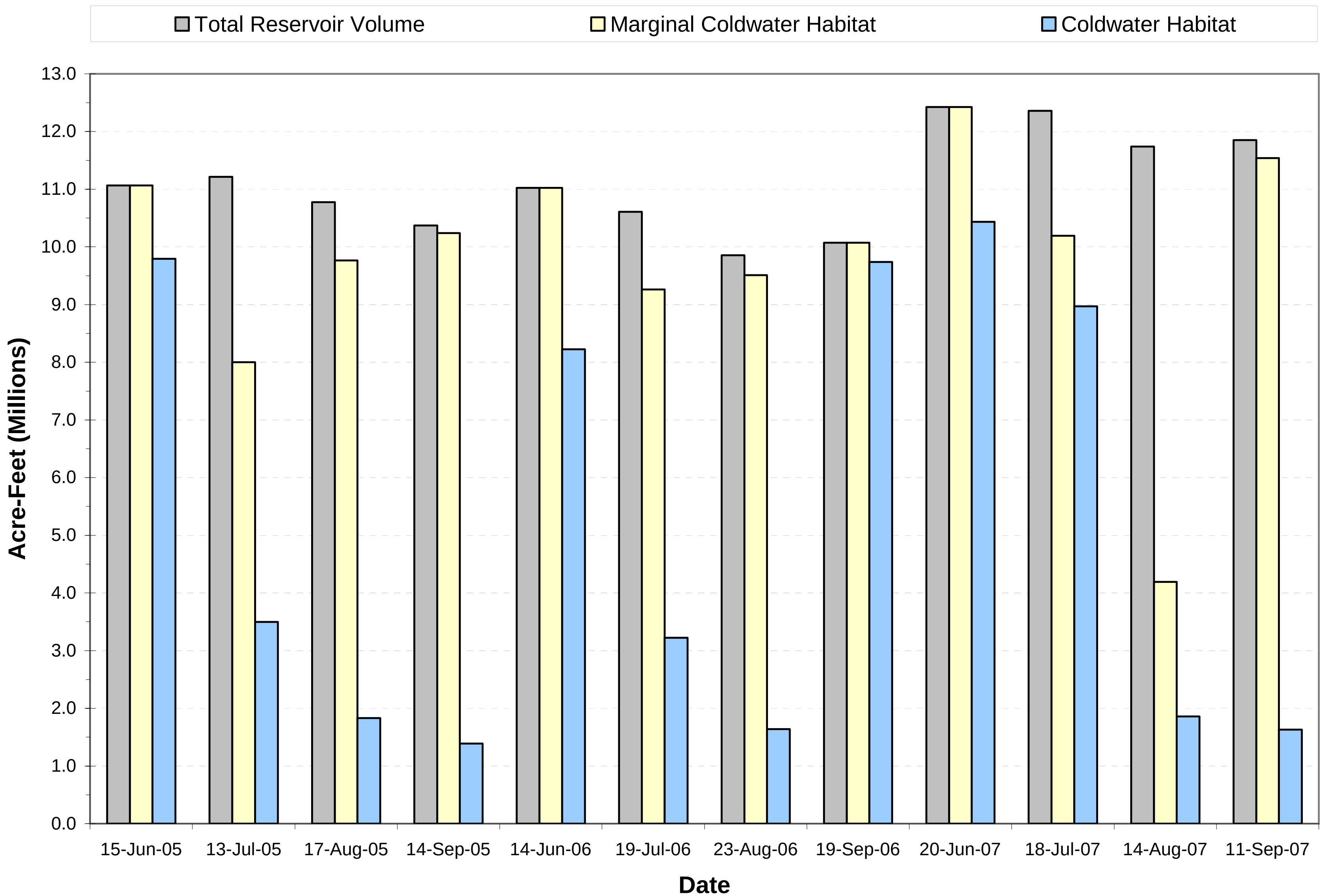

Figure 5.5. Total reservoir volume and the amount of coldwater habitat and marginal coldwater habitat estimated to be present in Oahe Reservoir during 2005, 2006, and 2007.

6 WATER QUALITY CONDITIONS OF INFLOWS TO OAHE RESERVOIR

6.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Statistical summaries of water quality conditions monitored at the two inflow sites, based on the collected grab samples, are given in Tables 6.1 through 6.4. Tables 6.1 and 6.2 summarize the water quality conditions that were monitored in the Missouri River near Bismarck, North Dakota (site NF1) during the 3-year period 2005 through 2007. Tables 6.3 and 6.4 summarize the water quality conditions that were monitored in the Cheyenne River near Eagle Butte, South Dakota (site NF2) during the 3-year period 2005 through 2007. Review of these results indicated no major water quality concerns. However, it is noted that the Cheyenne River, overall, has poor water quality. The river exhibited high levels of conductivity, dissolved solids, suspended solids, turbidity, chlorides, sulfates, iron, manganese, and detectable levels of several metals. The poor water quality in the Cheyenne River is believed to be a natural condition associated with the geology and soils of the river basin.

6.2 CONTINUOUS WATER TEMPERATURE MONITORING OF THE MISSOURI RIVER AT THE USGS GAGING STATION AT BISMARCK, NORTH DAKOTA

Figures 6.1 through 6.3, respectively, plot daily mean water temperature and streamflow for the Missouri River, as recorded at the USGS's Bismarck, North Dakota gaging station (USGS Gage Number 06342500) for calendar years 2005, 2006, and 2007.

Table 6.1. Summary of monthly (May through September) water quality conditions monitored in the Missouri River at Bismarck, North Dakota at monitoring Station OAHNFMORR1 (NF1) during the 3-year period 2005 through 2007**.**

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Stream Flow (cfs)	10	15	17,053	16,000	11,900	26,800	-----	-----	-----
Water Temperature (C)	0.1	15	19.4	18.7	14.8	25.5	18.3[1] 23.9[1] 26.7[1]	8 1 0	53% 7% 0%
Dissolved Oxygen (mg/l)	0.1	15	9.1	8.8	8.1	10.5	≥ 7.0[2] ≥ 6.0[2] ≥ 5.0[2]	0 0 0	0% 0% 0%
Dissolved Oxygen (% Sat.)	0.1	15	102.7	102.2	93.6	109.7	-----	-----	-----
Specific Conductance (umho/cm)	1	15	614	614	581	653	-----	-----	-----
pH (S.U.)	0.1	15	8.3	8.3	8.0	8.7	≥6.6 - ≤8.6[3] ≥6 5 - ≤8.8[3] ≥6 5 - ≤9.0[3]	1 0 0	7% 0% 0%
Turbidity (NTUs)	0.1	15	12.9	7.6	0.4	49.4	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	15	398	372	303	531	-----	-----	-----
Alkalinity, Total (mg/l)	7	15	160	155	140	185	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	15	-----	0.03	n.d.	0.08	3.88[4,5] 1.0[4,6]	0 0	0% 0%
Carbon, Total Organic (mg/l)	0.05	14	3.0	3.2	n.d.	4.0	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	11	10	11	2	16	-----	-----	-----
Chloride (mg/l)	1	10	9	9	8	10	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	14	442	425	390	620	1,750[7]	0	0%
Iron, Dissolved (ug/l)	40	15	-----	n.d.	n.d.	40	-----	-----	-----
Iron, Total (ug/l)	40	15	519	470	190	1,614	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	15	0.3	0.3	n.d.	0.7	-----	-----	-----
Manganese, Dissolved (ug/l)	1	15	-----	3	n.d.	10	-----	-----	-----
Manganese, Total (ug/l)	1	15	19	16	10	41	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	14	0.07	0.08	n.d.	0.11	10[7]	0	0%
Phosphorus, Total (mg/l)	0.01	15	0.10	0.04	n.d.	0.29	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	15	-----	0.02	n.d.	0.17	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	15	-----	n.d.	n.d.	0.06	-----	-----	-----
Sulfate (mg/l)	0.1	14	169	180	141	190	875[7]	0	0%
Suspended Solids, Total (mg/l)	4	15	16	15	6	27	53[5,8] 30[6,8]	0 0	0% 0%

n.d. = Not detected.

* Results are for samples collected at the surface.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (18.3 C), coldwater marginal fish life propagation (23.9 C), and warmwater permanent fish life propagation (26.7 C).

(2) Numeric dissolved oxygen criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (7 mg/l in spawning areas during spawning season and 6 mg/l at other times), coldwater marginal fish life propagation (5 mg/l), and warmwater permanent fish life propagation (5 mg/l).

(3) Numeric pH criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (≥6.6 - ≤8.6), coldwater marginal fish life propagation (≥65 - ≤8.8), and warmwater permanent fish life propagation (≥6.5 - ≤9.0).

(4) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values. Listed criteria are those defined by South Dakota's water quality standards for the protection of coldwater permanent fish life propagation.

(5) Acute criterion for aquatic life.

(6) Chronic criterion for aquatic life.

(7) Daily maximum criterion for domestic water supply.

(8) Numeric suspended solids criteria given in South Dakota's water quality standards for coldwater permanent fish life propagation.

Table 6.2. Summary of annual (May and August) water quality conditions monitored in the Missouri River at Bismarck, North Dakota at monitoring Station OAHNFMORR1 (NF1) during the 3-year period 2005 through 2007**.**

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Hardness, Dissolved (mg/l)	0.4	2	200	200	181	219	-----	-----	-----
Aluminum, Dissolved (ug/l)	50	1	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	5.6(3)	0	0%
Arsenic, Dissolved (ug/l)	1	1	-----	1	1	1	340(1) 150(2) 0.018(3)	0 0 1	0% 0% 100%
Beryllium, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	4(3)	0	0%
Cadmium, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	9.9(1) 4.2(2)	0 0	0% 0%
Chromium, Dissolved (ug/l)	2	2	-----	n.d.	n.d.	n.d.	3,180(1) 152(2)	0 0	0% 0%
Copper, Dissolved (ug/l)	2	2	-----	n.d.	n.d.	n.d.	26.9(1) 16.9(2)	0 0	0% 0%
Lead, Dissolved (ug/l)	2	2	-----	n.d.	n.d.	n.d.	197(1) 7.7(2)	0 0	0% 0%
Mercury, Dissolved (ug/l)	0.02	2	-----	n.d.	n.d.	n.d.	1.4(1) 0.05(3)	0 0	0% 0%
Mercury, Total (ug/l)	0.02	2	-----	n.d.	n.d.	n.d.	0.012(2)	b.d.	b.d.
Nickel, Dissolved (ug/l)	3	2	-----	n.d.	n.d.	n.d.	843(1) 94(2) 610(3)	0 0 0	0% 0% 0%
Selenium, Total (ug/l)	4	1	-----	n.d.	n.d.	n.d.	4.6(2) 170(3)	0 0	0% 0%
Silver, Dissolved (ug/l)	1	2	-----	n.d.	n.d.	n.d.	14.7(1)	0	0%
Zinc, Dissolved (ug/l)	3	1	3	3	3	3	216(1,2) 7,400(3)	0 0	0% 0%
Pesticide Scan (ug/l)****	0.05	1	-----	n.d.	n.d.	n.d.	*****	0	0%

n.d. = Not detected. b.d. = Criteria below detection limit.

* Results are for samples collected at the surface. Metals samples were collected on August 28, 2006 and August 20, 2007. Pesticide sample was collected on May 25, 2006.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.

*** (1) Acute criterion for aquatic life.
(2) Chronic criterion for aquatic life.
(3) Human health criterion.

Note: South Dakota's water quality standards criteria for the metals cadmium, chromium, copper, lead, nickel, silver, and zinc are dependent upon hardness – criteria listed are based on the median hardness value.

**** The pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, cycloate, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, phorate, profluralin, prometon, propachlor, propazine, simazine, terbufos, triallate, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

***** Some pesticides do not have water quality standards criteria defined, and for those pesticides that have criteria, the criteria vary.

Table 6.3. Summary of monthly (May through September) water quality conditions monitored in the Cheyenne River Near eagle Butte, South Dakota at monitoring Station OAHNFCHYR1 (NF2) during the 3-year period 2005 through 2007**.**

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	**No. of Obs.**	**Mean****	**Median**	**Min.**	**Max.**	**State WQS Criteria*****	**No. of WQS Exceedences**	**Percent WQS Exceedence**
Stream Flow (cfs)	10	14	342	243	117	1,335	-----	-----	-----
Water Temperature (C)	0.1	13	22.7	23.0	12.0	32.7	18.3[(1)] 23.9[(1)] 26.7[(1)]	10 5 4	77% 38% 31%
Dissolved Oxygen (mg/l)	0.1	13	8.0	8.0	5.4	9.7	≥ 7.0[(2)] ≥ 6.0[(2)] ≥ 5.0[(2)]	2 1 0	15% 8% 0%
Dissolved Oxygen (% Sat.)	0.1	13	96.9	96.3	65.8	118.4	-----	-----	-----
Specific Conductance (umho/cm)	1	13	1,832	1,794	1,135	3,033	-----	-----	-----
pH (S.U.)	0.1	13	8.2	8.2	7.8	8.5	≥6.6 - ≤8.6[(3)] ≥6 5 - ≤8.8[(3)] ≥6 5 - ≤9.0[(3)]	0 0 0	0% 0% 0%
Turbidity (NTUs)	0.1	13	502	158	41	1,403	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	13	381	369	273	470	-----	-----	-----
Alkalinity, Total (mg/l)	7	14	133	120	92	203	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	14	-----	0.06	n.d.	0.26	3.15[(4,5)] 1.11[(4,6)]	0 0	0% 0%
Carbon, Total Organic (mg/l)	0.05	13	4.8	4.6	3.4	6.2	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	10	27	23	8	68	-----	-----	-----
Chloride (mg/l)	1	10	40	38	14	71	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	14	1,512	1,558	433	2,300	1,750[(7)]	4	29%
Iron, Dissolved (ug/l)	40	14	-----	n.d.	n.d.	2,219	-----	-----	-----
Iron, Total (ug/l)	40	14	112,517	7,748	n.d.	1,047,000	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	14	2.8	1.2	0.6	19.0	-----	-----	-----
Manganese, Dissolved (ug/l)	1	14	17	11	n.d.	67	-----	-----	-----
Manganese, Total (ug/l)	1	14	1,859	214	15	17,186	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	14	-----	0.04	n.d.	0.93	10[(7)]	0	0%
Phosphorus, Total (mg/l)	0.01	14	2.86	0.33	0.09	27.00	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	14	-----	0.03	n.d.	1.00	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	14	-----	n.d.	n.d.	0.50	-----	-----	-----
Sulfate (mg/l)	0.1	12	974	962	385	1,700	875[(7)]	7	58%
Suspended Solids, Total (mg/l)	4	14	4,557	305	51	45,000	53[(5,8)] 30[(6,8)]	13 14	93% 100%

n.d. = Not detected.

* Results are for samples collected at the surface.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (18.3 C), coldwater marginal fish life propagation (23.9 C), and warmwater permanent fish life propagation (26.7 C).

(2) Numeric dissolved oxygen criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (7 mg/l in spawning areas during spawning season and 6 mg/l at other times), coldwater marginal fish life propagation (5 mg/l), and warmwater permanent fish life propagation (5 mg/l).

(3) Numeric pH criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (≥6.6 - ≤8.6), coldwater marginal fish life propagation (≥65 - ≤8.8), and warmwater permanent fish life propagation (≥6.5 - ≤9.0).

(4) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values. Listed criteria are those defined by South Dakota's water quality standards for the protection of coldwater permanent fish life propagation.

(5) Acute criterion for aquatic life.

(6) Chronic criterion for aquatic life.

(7) Daily maximum criterion for domestic water supply.

(8) Numeric suspended solids criteria given in South Dakota's water quality standards for coldwater permanent fish life propagation.

Table 6.4. Summary of annual (May and August) water quality conditions monitored in the Cheyenne River Near Eagle Butte, South Dakota at monitoring Station OAHNFCHYR1 (NF2) during the 3-year period 2005 through 2007**.**

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Hardness, Dissolved (mg/l)	0.4	1	350	350	350	350	-----	-----	-----
Aluminum, Dissolved (ug/l)	50	1	1,831	1,831	1,831	1,831.	-----	-----	-----
Antimony, Dissolved (ug/l)	0.5	1	0.6	0.6	0.6	0.6	5.6(3)	0	0%
Arsenic, Dissolved (ug/l)	1	1	7	7	7	7	340(1) 150(2) 0.018(3)	0 0 1	0% 0% 100%
Beryllium, Dissolved (ug/l)	0.5	1	-----	n.d.	n.d.	n.d.	4(3)	0	0%
Cadmium, Dissolved (ug/l)	0.5	1	-----	n.d.	n.d.	n.d.	9.9(1) 4.2(2)	0 0	0% 0%
Chromium, Dissolved (ug/l)	2	1	4	4	4	4	3,180(1) 152(2)	0 0	0% 0%
Copper, Dissolved (ug/l)	2	1	4	4	4	4	26.9(1) 16.9(2)	0 0	0% 0%
Lead, Dissolved (ug/l)	2	1	-----	n.d.	n.d.	n.d.	197(1) 7.7(2)	0 0	0% 0%
Mercury, Dissolved (ug/l)	0.02	1	-----	n.d.	n.d.	n.d.	1.4(1) 0.05(3)	0 0	0% 0%
Mercury, Total (ug/l)	0.02	1	0.1	0.1	0.1	0.1	0.012(2)	1	100%
Nickel, Dissolved (ug/l)	3	1	3	3	3	3	843(1) 94(2) 610(3)	0 0 0	0% 0% 0%
Silver, Dissolved (ug/l)	1	1	-----	n.d.	n.d.	n.d.	14.7(1)	0	0%
Zinc, Dissolved (ug/l)	3	1	29	29	29	29	216(1,2) 7,400(3)	0 0	0% 0%

n.d. = Not detected. b.d. = Criteria below detection limit.

* Results are for samples collected at the surface. Metals sample was collected on August 15, 2007.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.

*** (1) Acute criterion for aquatic life..

(2) Chronic criterion for aquatic life..

(3) Human health criterion.

Note: South Dakota's water quality standards criteria for the metals cadmium, chromium, copper, lead, nickel, silver, and zinc are dependent upon hardness – criteria listed are based on the median hardness value.

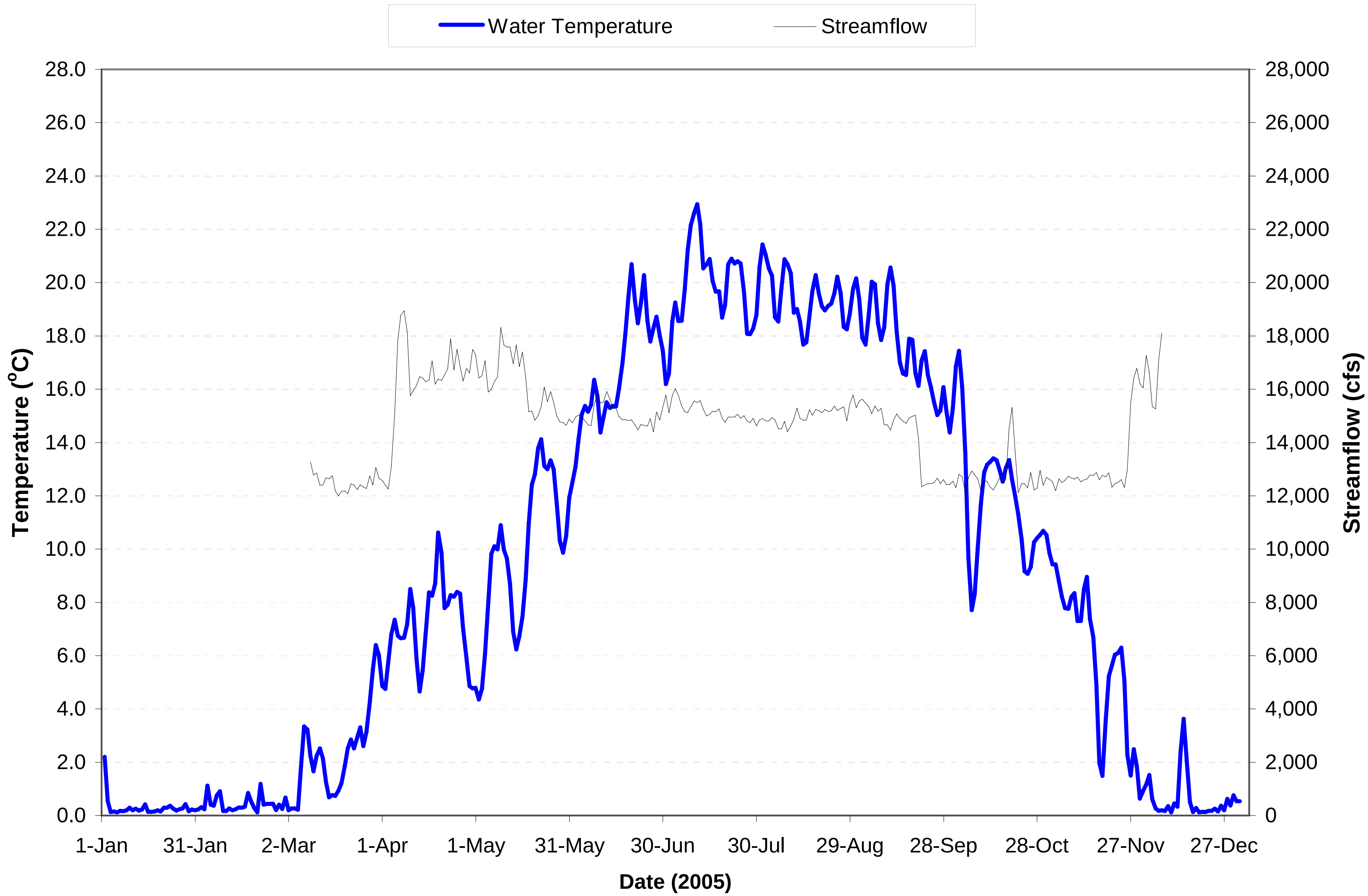

Figure 6.1. Mean daily water temperature and streamflow of the Missouri River at inflow site NF1 (OAHNFMORR1) for 2005. Means based on hourly measurements recorded at USGS gaging station 06342500. (Gaps in plot indicate missing data.)

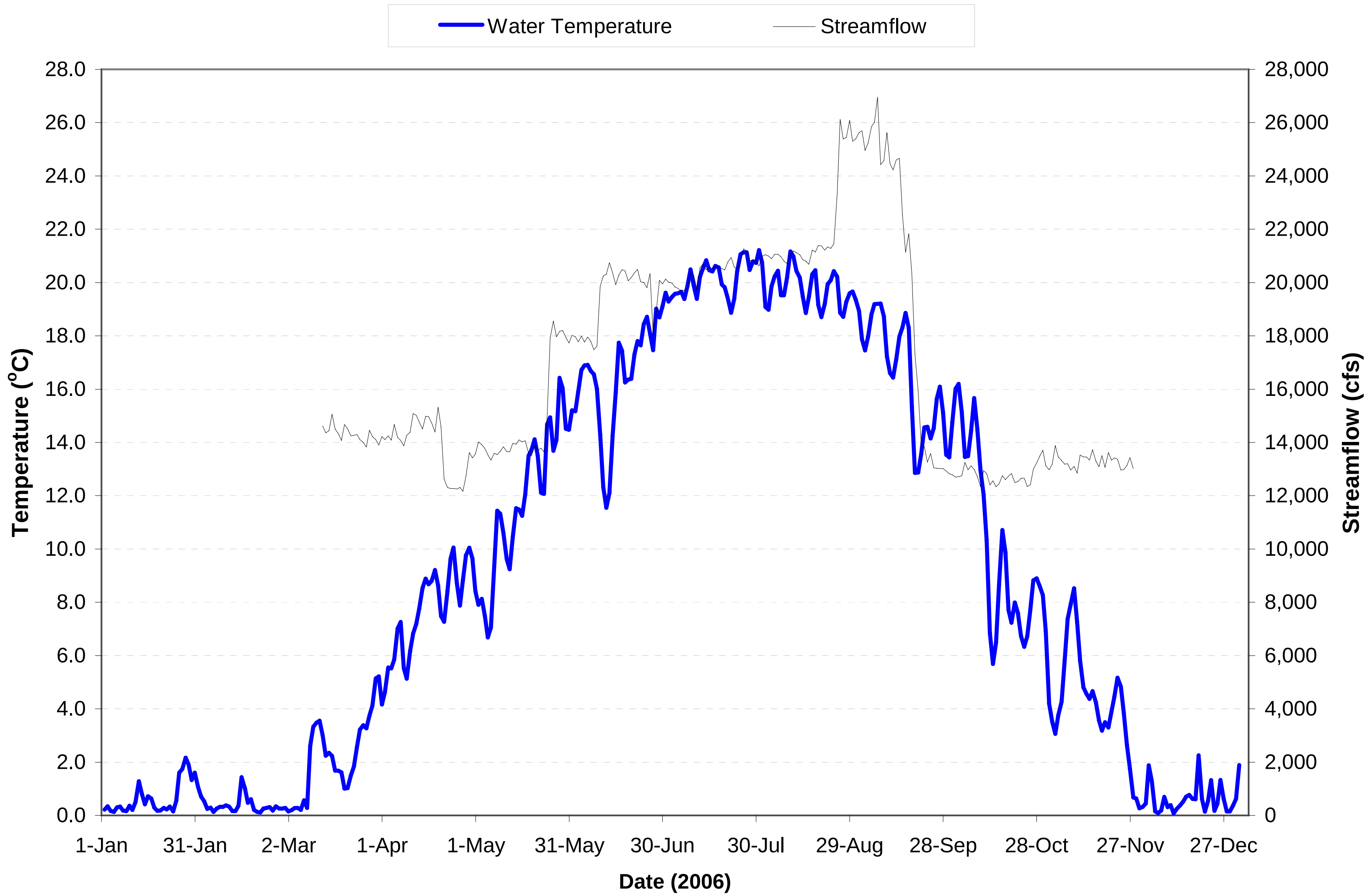

Figure 6.2. Mean daily water temperature and streamflow of the Missouri River at inflow site NF1 (OAHNFMORR1) for 2006. Means based on hourly measurements recorded at USGS gaging station 06342500. (Gaps in plot indicate missing data).

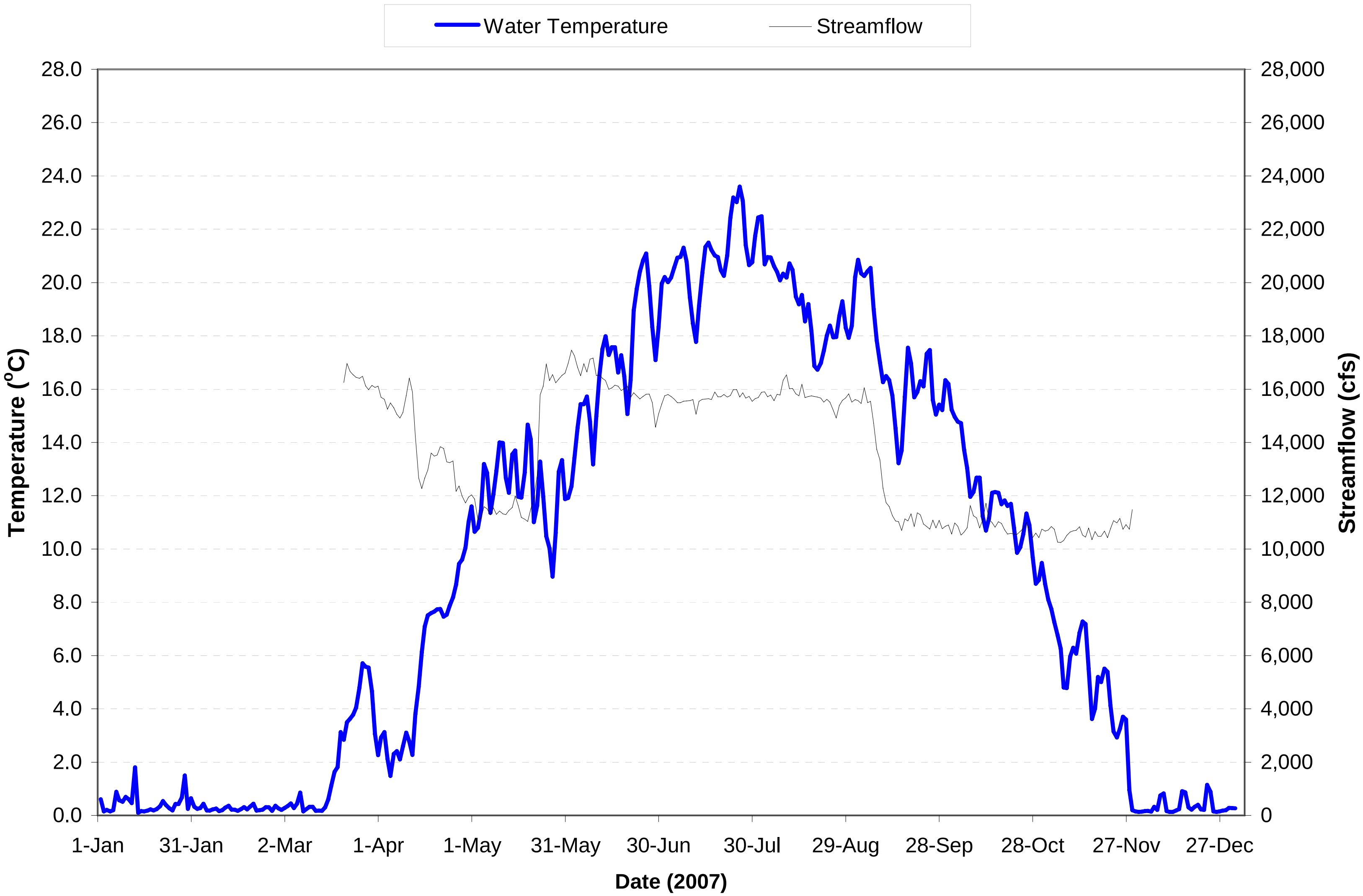

Figure 6.3. Mean daily water temperature and streamflow of the Missouri River at inflow site NF1 (OAHNFMORR1) for 2007. Means based on hourly measurements recorded at USGS gaging station 06342500. (Gaps in plot indicate missing data).

7 WATER QUALITY CONDITIONS OF THE MISSOURI RIVER DOWNSTREAM OF OAHE DAM

7.1 WATER QUALITY CONDITIONS OF WATER DISCHARGED THROUGH OAHE DAM

7.1.1 STATISTICAL SUMMARY AND WATER QUALITY STANDARDS ATTAINMENT

Table 7.1 summarizes the water quality conditions that were monitored monthly on water discharged through the Oahe powerplant during the 3-year period 2005 through 2007. These results indicate no major water quality standards concerns. However, it is noted that 29% of the water temperature measurements exceeded the 18.3°C criterion identified for the protection of the coldwater permanent fish life propagation use which is designated to the Missouri River downstream of Oahe Dam.

7.1.2 CONTINUOUS MONITORING OF WATER QUALITY CONDITIONS OF WATER DISCHARGED THROUGH THE OAHE POWERPLANT

Continuous monitoring (i.e., hourly measurements) of water passed through the Oahe powerplant and discharged to the Missouri River downstream of the dam was conducted year-round during the 3-year period of 2005 through 2007. Water quality parameters monitored at site OAHPP1 (i.e., OF1) included water temperature, dissolved oxygen, and conductivity. The average hourly discharge of water through the powerplant turbines was compiled from project records.

7.1.3 WATER TEMPERATURE

Plots of the hourly water temperatures and average dam discharge for the 3 years 2005, 2006, and 2007 are shown in Plates 54 through 65. During the January through March period, water temperatures remained around 2°C (Plates 54, 58, and 62). From April through June, water temperatures exhibited a steady increase to a maximum of about 20°C at the end of June (Plates 55, 59, and 63). During the July through September period, water temperatures increased from around 20°C, at the start of July, to a high of around 24°C in early August, and then fell back to around 20°C by mid- to late-September (Plates 56, 60, and 64). From October through December, water temperatures steadily declined from around 20°C to about 4°C (Plates 57, 61, and 65). Water temperatures monitored over the 3-year period exhibited little observable correlation to the dam discharge rate (Plates 54 - 65).

7.1.4 DISSOLVED OXYGEN

Plots of the hourly dissolved oxygen concentrations and average dam discharge for the 2 years 2006 and 2007 are shown in Plates 66 through 73. It is noted that the dissolved oxygen monitoring equipment installed in the Oahe powerplant during 2005 malfunctioned and credible dissolved oxygen data were not collected. During the January through March period, monitored dissolved oxygen levels were fairly stable at about 13 mg/l (Plates 66 and 70). From April through June, dissolved oxygen levels steadily declined to about 8.5 mg/l at the end June (Plates 67 and 71). During the July through September period, monitored dissolved oxygen levels decreased from around 8.5 mg/l, at the start of July, to a low of around 7 mg/l in early August, and then rose back to around 8.5 mg/l by late-September (Plates 68 and 72). From October through December, dissolved oxygen levels steadily increased from about 8.5 to around 12 mg/l. Dam discharge rates appeared to have little affect on the dissolved oxygen levels monitored during 2006 and 2007.

Table 7.1. Summary of monthly (May through September) water quality conditions monitored on water discharged through the Oahe powerplant at monitoring Station OAHPP1 (OF1) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Pool Elevation (ft-msl)	0.1	32	1576.2	1576.0	1571.4	1583.2	-----	-----	-----
Dam Discharge (cfs)	10	32	18,476	18,050	0	42,000	-----	-----	-----
Water Temperature (C)	0.1	31	11.8	11.3	1.5	23.2	18.3[(1)] 23.9[(1)] 26.7[(1)]	9 0 0	29% 0% 0%
Dissolved Oxygen (mg/l)	0.1	31	10.1	10.2	7.1	13.6	≥ 7.0[(2)] ≥ 6.0[(2)] ≥ 5.0[(2)]	0 0 0	0% 0% 0%
Dissolved Oxygen (% Sat.)	0.1	31	95.6	96.2	80.8	105.7	-----	-----	-----
Specific Conductance (umho/cm)	1	31	657	682	357	736	-----	-----	-----
pH (S.U.)	0.1	24	8.3	8.3	8.0	8.6	≥6.6 - ≤8.6[(3)] ≥6 5 - ≤8.8[(3)] ≥6 5 - ≤9.0[(3)]	0 0 0	0% 0% 0%
Turbidity (NTUs)	0.1	12	2.4	2.1	n.d.	8.6	-----	-----	-----
Oxidation-Reduction Potential (mV)	1	14	396	382	274	541	-----	-----	-----
Alkalinity, Total (mg/l)	7	31	171	170	140	202	-----	-----	-----
Ammonia N, Total (mg/l)	0.01	31	-----	0.01	n.d.	0.25	3.15[(4,5)] 1.11[(4,6)]	0 0	0% 0%
Carbon, Total Organic (mg/l)	0.05	29	3.0	2.9	1.2	4.3	-----	-----	-----
Chemical Oxygen Demand (mg/l)	2	20	8	7	n.d.	19	-----	-----	-----
Chloride (mg/l)	1	18	11	11	9	14	-----	-----	-----
Dissolved Solids, Total (mg/l)	5	31	465	456	416	570	1,750[(7)]	0	0%
Iron, Dissolved (ug/l)	40	24	-----	n.d.	n.d.	50	-----	-----	-----
Iron, Total (ug/l)	40	24	109	60	n.d.	540	-----	-----	-----
Kjeldahl N, Total (mg/l)	0.1	31	0.4	0.3	n.d.	1.8	-----	-----	-----
Manganese, Dissolved (ug/l)	1	24	-----	n.d.	n.d,	16	-----	-----	-----
Manganese, Total (ug/l)	1	24	16	10	n.d.	66	-----	-----	-----
Nitrate-Nitrite N, Total (mg/l)	0.02	31	-----	n.d.	n.d.	0.09	10[(7)]	0	0%
Phosphorus, Total (mg/l)	0.01	31	-----	0.03	n.d.	0.29	-----	-----	-----
Phosphorus, Total Dissolved (mg/l)	0.01	22	-----	n.d.	n.d.	0.20	-----	-----	-----
Orthophosphorus, Dissolved (mg/l)	0.01	31	-----	n.d.	n.d.	0.03	-----	-----	-----
Sulfate (mg/l)	0.1	31	199	200	163	230	875[(7)]	0	0%
Suspended Solids, Total (mg/l)	4	31	-----	n.d.	n.d.	91	53[(5,8)] 30[(6,8)]	1 1	3% 3%

n.d. = Not detected.

* Results are for samples collected at the surface.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported. The mean value reported for pH is an arithmetic mean based on measured values (i.e., log conversion of logarithmic pH values was not done to calculate mean).

*** (1) Numeric temperature criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (18.3 C), coldwater marginal fish life propagation (23.9 C), and warmwater permanent fish life propagation (26.7 C).

(2) Numeric dissolved oxygen criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (7 mg/l in spawning areas during spawning season and 6 mg/l at other times), coldwater marginal fish life propagation (5 mg/l), and warmwater permanent fish life propagation (5 mg/l).

(3) Numeric pH criteria are given in South Dakota's water quality standards for coldwater permanent fish life propagation (≥6.6 - ≤8.6), coldwater marginal fish life propagation (≥65 - ≤8.8), and warmwater permanent fish life propagation (≥6.5 - ≤9.0).

(4) Total ammonia criteria pH and temperature dependent – criteria listed are for the median pH and temperature values. Listed criteria are those defined by South Dakota's water quality standards for the protection of coldwater permanent fish life propagation.

(5) Acute criterion for aquatic life.

(6) Chronic criterion for aquatic life.

(7) Daily maximum criterion for domestic water supply.

(8) Numeric suspended solids criteria given in South Dakota's water quality standards for coldwater permanent fish life propagation.

Table 7.2. Summary of annual (May and August) water quality conditions monitored on water discharged through the Oahe powerplant at monitoring site OAHPP1 (OF1) during the 3-year period 2005 through 2007.

Parameter	Monitoring Results*						Water Quality Standards Attainment		
	Detection Limit	No. of Obs.	Mean**	Median	Min.	Max.	State WQS Criteria***	No. of WQS Exceedences	Percent WQS Exceedence
Hardness, Dissolved (mg/l)	0.4	2	224	224	213	235	-----	-----	-----
Aluminum, Dissolved (ug/l)	50	2	-----	n.d.	n.d.	n.d.	-----	-----	-----
Antimony, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	5.6(3)	0	0%
Arsenic, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	1	340(1) 150(2) 0.018(3)	0 0 b.d.	0% 0% b.d.
Beryllium, Dissolved (ug/l)	0.5	2	-----	n.d.	n.d.	n.d.	4(3)	0	0%
Cadmium, Dissolved (ug/l)	0.5	5	-----	n.d.	n.d.	n.d.	11.2(1) 4.6(2)	0 0	0% 0%
Chromium, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	3,490(1) 169(2)	0 0	0% 0%
Copper, Dissolved (ug/l)	2	5	-----	3	n.d.	6	29.9(1) 18.6(2)	0 0	0% 0%
Lead, Dissolved (ug/l)	2	5	-----	n.d.	n.d.	n.d.	228(1) 8.9(2)	0 0	0% 0%
Mercury, Dissolved (ug/l)	0.02	6	-----	n.d.	n.d.	n.d.	1.4(1) 0.05(3)	0 0	0% 0%
Mercury, Total (ug/l)	0.02	6	-----	n.d.	n.d.	n.d.	0.012(2)	b.d.	b.d.
Nickel, Dissolved (ug/l)	3	5	-----	n.d.	n.d.	n.d.	928(1) 103(2) 610(3)	0 0 0	0% 0% 0%
Silver, Dissolved (ug/l)	1	5	-----	n.d.	n.d.	n.d.	14.7(1)	0	0%
Zinc, Dissolved (ug/l)	3	4	5	4	3	11	237(1,2) 7,400(3)	0 0	0% 0%
Pesticide Scan (ug/l)****	0.05	1	-----	n.d.	n.d.	n.d.	*****	0	0%

n.d. = Not detected. b.d. = Criteria below detection limit.

* Results are for samples collected at the surface. Metals sample was collected on August 15, 2007.

** Nondetect values set to 0 to calculate mean. If 20% or more of observations were nondetect, mean is not reported.

*** (1) Acute criterion for aquatic life..

(2) Chronic criterion for aquatic life..

(3) Human health criterion.

Note: South Dakota's water quality standards criteria for the metals cadmium, chromium, copper, lead, nickel, silver, and zinc are dependent upon hardness – criteria listed are based on the median hardness value.

**** The pesticide scan includes: acetochlor, alachlor, ametryn, atrazine, benfluralin, bromacil, butachlor, butylate, chlorpyrifos, cyanazine, cycloate, dimethenamid, diuron, EPTC, ethalfluralin, fonofos, hexazinone, isophenphos, isopropalin, metolachlor, metribuzin, molinate, oxadiazon, oxyfluorfen, pebulate, pendimethalin, phorate, profluralin, prometon, propachlor, propazine, simazine, terbufos, triallate, trifluralin, and vernolate. Individual pesticides were not detected unless listed under pesticide scan.

***** Some pesticides do not have water quality standards criteria defined, and for those pesticides that have criteria, the criteria vary.

7.2 COMPARISON OF MONITORED INFLOW AND OUTFLOW TEMPERATURES OF THE MISSOURI RIVER AT OAHE RESERVOIR

Figures 7.1 through 7.3, respectively, plot the mean daily water temperatures monitored at the Missouri River near Bismarck, North Dakota (site NF1) and the Oahe Dam powerplant (site OF1) during 2005, 2006, and 2007. Inflow temperatures of the Missouri River to Oahe Reservoir are generally warmer than the outflow temperatures of Oahe Dam during the period of April through June (Figures 7.1 - 7.3). Outflow temperatures of the Oahe Dam discharge are generally warmer than the inflow temperatures of the Missouri River during the period of July through March (Figures 7.1 - 7.3). A maximum temperature difference occurs in the late-fall and early-winter when the Oahe Dam discharge temperature is about 4°C warmer than the Missouri River inflow temperature (Figures 7.1 - 7.3).

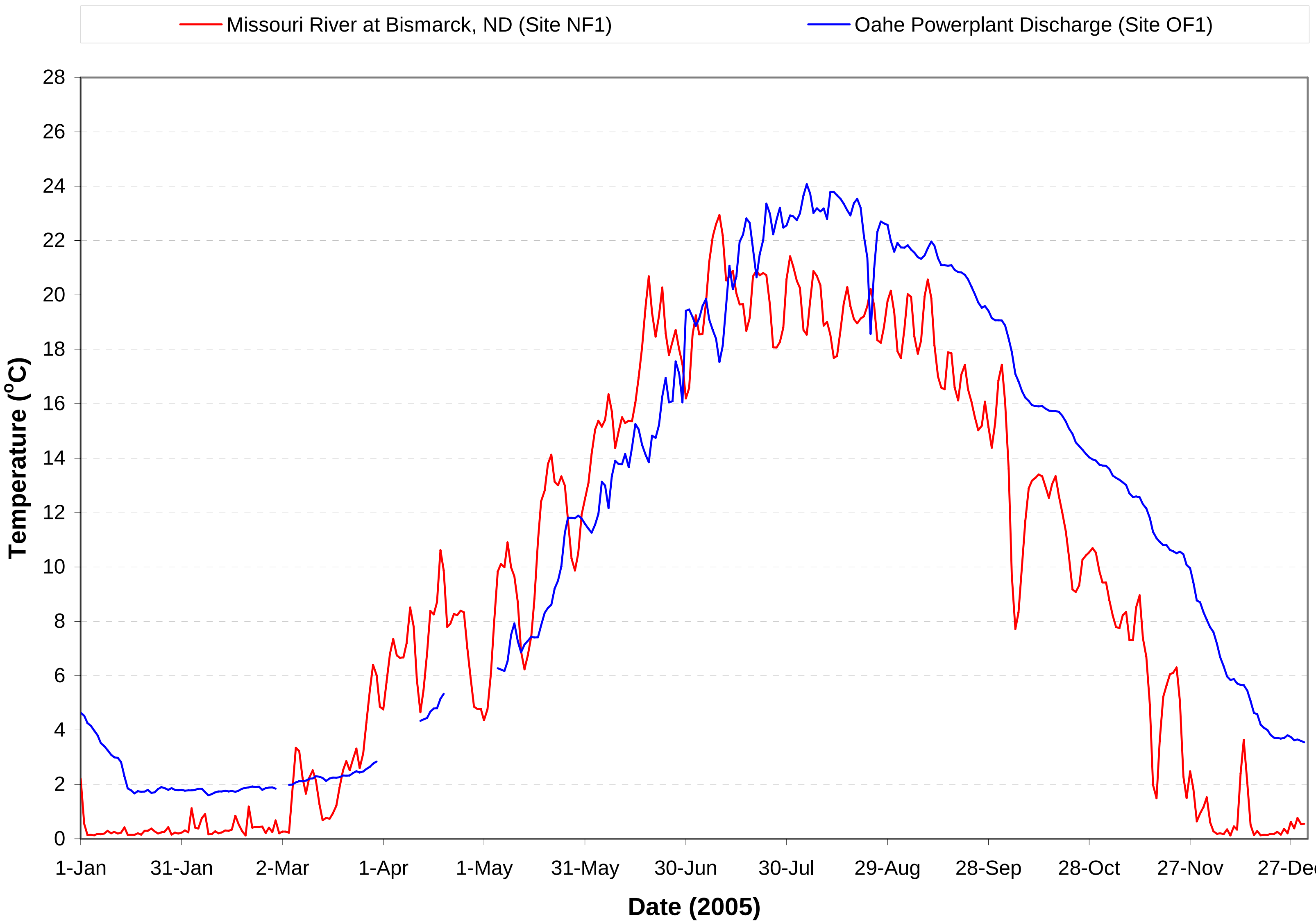

Figure 7.1. Mean daily water temperatures monitored at the Oahe powerplant and the Missouri at Bismarck, North Dakota for 2005. (Note: Gaps in temperature plots are periods when monitoring equipment was not operational.)

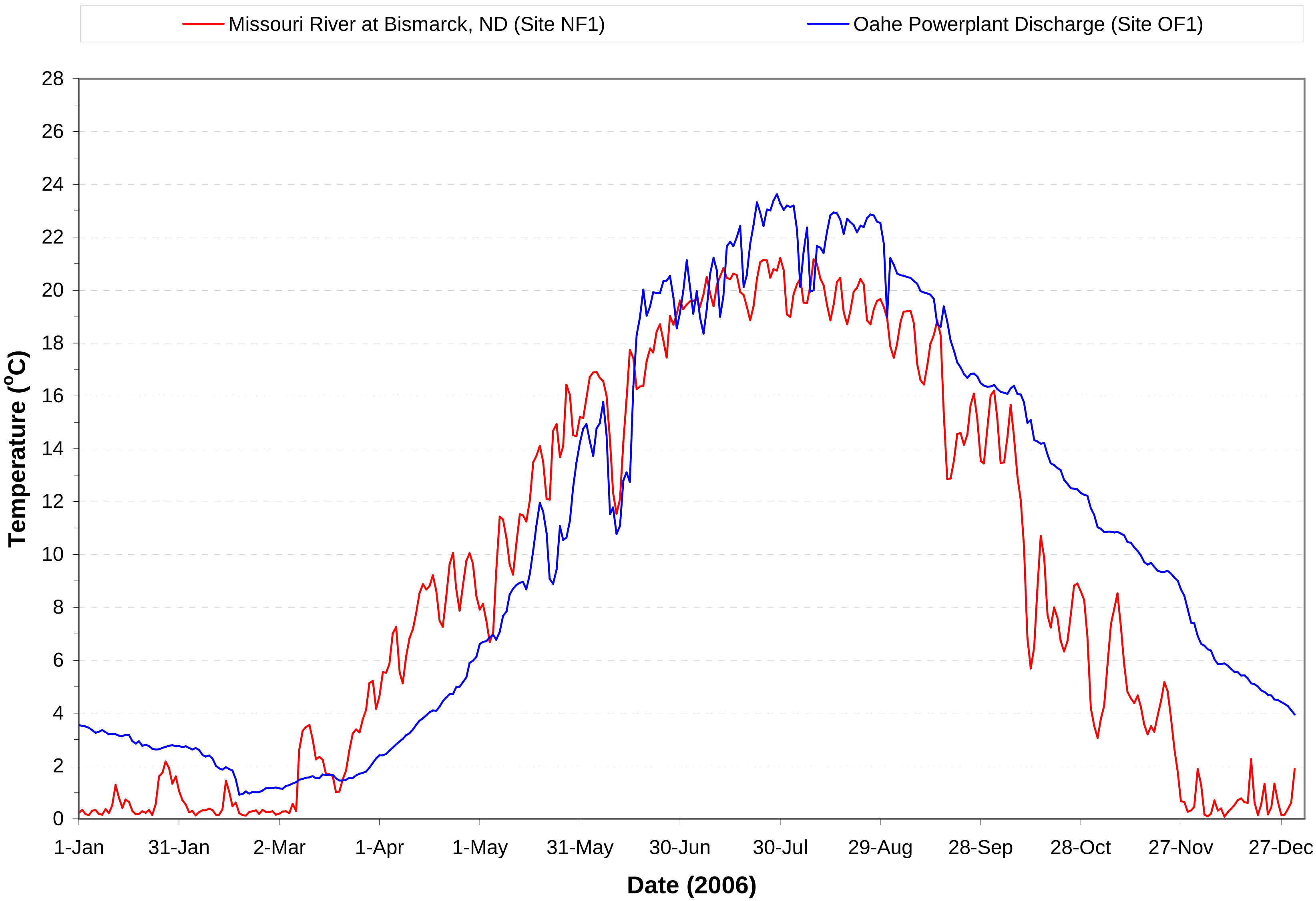

Figure 7.2. Mean daily water temperatures monitored at the Oahe powerplant and the Missouri at Bismarck, North Dakota for 2006.

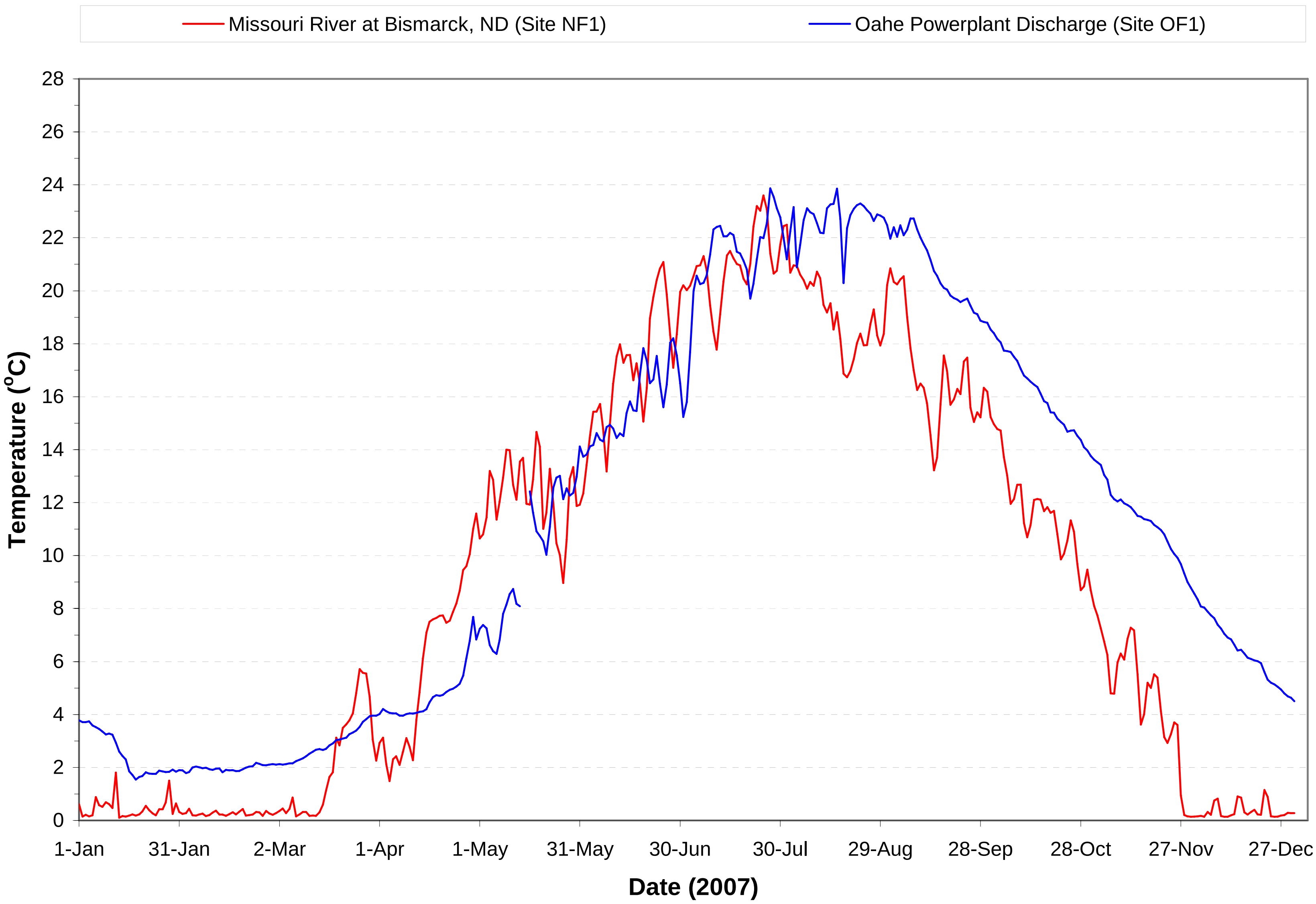

Figure 7.3. Mean daily water temperatures monitored at the Oahe powerplant and the Missouri at Bismarck, North Dakota for 2007. (Note: Gaps in temperature plots are periods when monitoring equipment was not operational.)

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 EXISTING WATER QUALITY CONDITIONS

8.1.1 OAHE RESERVOIR

Water quality monitoring of Oahe Reservoir during the 3-year period of 2005 through 2007 indicated good water quality conditions in the reservoir. Water quality conditions in Oahe Reservoir vary along the length of the reservoir. Strong thermal stratification occurs in the deeper area of the reservoir nearer Oahe Dam during the summer. Water quality monitoring indicated that the trophic status of the downstream half of the reservoir is mesotrophic; while the upstream half is moderately eutrophic to eutrophic. The phytoplankton community of Oahe Reservoir was dominated by diatoms and only minor "blooms" of cyanobacteria were monitored.

8.1.2 WATER DISCHARGED THROUGH OAHE DAM

Water discharged through Oahe Dam exhibited good water quality during the monitored 3-year period of 2005 through 2007. The temperature of the discharge water is reflective of the mid-depth elevation of its withdrawal from Oahe Reservoir. During drought conditions when reservoir pool levels are low, the invert elevation of the intake for the power tunnels is at or above the elevation of the thermocline during summer thermal stratification of the reservoir. Under these conditions, the temperature of water discharged through Oahe Dam is reflective of the water temperatures near the reservoir surface. Under higher pool elevations during normal or high water conditions, the temperature of water discharge through Oahe Dam during the summer could seemingly be more reflective of the cooler metalimnetic and hypolimnetic conditions present in the reservoir.

8.2 COLDWATER HABITAT IN OAHE RESERVOIR

The State of South Dakota, in their water quality standards, identified coldwater permanent fish life propagation as a designated use for Oahe Reservoir. To protect for this use, South Dakota's water quality standards state that water temperature should not exceed 65°F (18.3°C). These standards also state that dissolved oxygen concentrations should remain above 6 mg/l (7 mg/l in spawning areas during the spawning season). During the 3-year period 2005 through 2007, the amount of coldwater habitat, support of the coldwater permanent fish life propagation use, estimated to be present in Oahe Reservoir in June, July, August and September ranged from a high of 10.4 million ac-ft (June 2007) to a low of about 1.4 million acre-ft (August 2006). The volume of coldwater habitat present in Oahe Reservoir during the summer is determined by the thermal stratification of the reservoir, and dissolved oxygen degradation in the hypolimnion near the reservoir bottom.

8.3 WATER QUALITY MANAGEMENT

The Omaha District is planning to pursue the application of the Corps' CE-QUAL-W2 (Version 3.2) hydrodynamic and water quality model to Oahe Reservoir. CE-QUAL-W2 is an extremely powerful tool to aid in addressing reservoir water quality management issues. Application of the CE-QUAL-W2 model will allow the Corps to better understand how the operation of the Oahe Project affects the water quality of Oahe Reservoir and the Missouri River below Oahe Dam. It is almost a certainty that water quality issues at the Oahe Project will remain important in the future.

8.4 WATER QUALITY MONITORING RECOMMENDATIONS

Continue monthly (i.e., May, June, July, August, and September) monitoring of ambient water quality conditions in Oahe Reservoir at four sites, and on the Missouri River inflow to the reservoir. Continue year-round monitoring (i.e., monthly water samples and hourly data-logging) of water drawn from the raw-water supply line in the Oahe powerplant.

9 REFERENCES

Carlson, R.E. 1977. A trophic state index for lakes. Limnology and Oceanography, March 1977, Vol 22(2), pp. 361-369.

Cole, Thomas M., Schneider, M.L., Skogerboe, J.G., Heath, R.E., and Turner, H.O. 1994. Temperature and dissolved oxygen simulations for the Upper Missouri River Reservoirs, Miscellaneous Report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hydrogeologic, Inc. 2005. Data Management and Analysis System for Lakes, Estuaries, and Rivers – Generic Version (DASLER-X). Version 4.5. HydroGeoLogic, Inc., Maryville, TN.

U.S. Army Corps of Engineers. 1987. Engineer Manual (EM) 1110-2-1201, Engineering and design – Reservoir Water Quality Analysis. U.S. Army Corps of Engineers, Department of the Army, Washington, DC.

_______. **2003.** Collection of Surface Water Samples. SOP Number: WQ-21101. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers, Omaha, Nebraska.

_______. **2004a.** Missouri River Mainstem Reservoir System, Master Water Control Manual. U.S. Army Corps of Engineers, Northwestern Division, Missouri River Basin, Reservoir Control Center, Omaha, NE.

_______. **2004b.** Determining Secchi Depth. SOP Number: WQ-21202. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers, Omaha, Nebraska.

_______. **2006.** Using a "Hydrolab 4, 4a, and 5" to directly measure water quality. SOP Number: WQ-21201. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers, Omaha, Nebraska.

_______. **2008.** Program management plan for implementing the Omaha District's water quality management program. Water Quality Unit, Water Control and Water Quality Section, Hydrologic Engineering Branch, Engineering Division, Omaha District, U.S. Army Corps of Engineers, Omaha, Nebraska.

U.S. Fish and Wildlife Service. 1993. Recovery plan for the pallid sturgeon (*Scaphirhynchus albus*). Pallid sturgeon recovery team. Region 6, U.S. Fish and Wildlife Service, Denver, Colorado.

10 PLATES

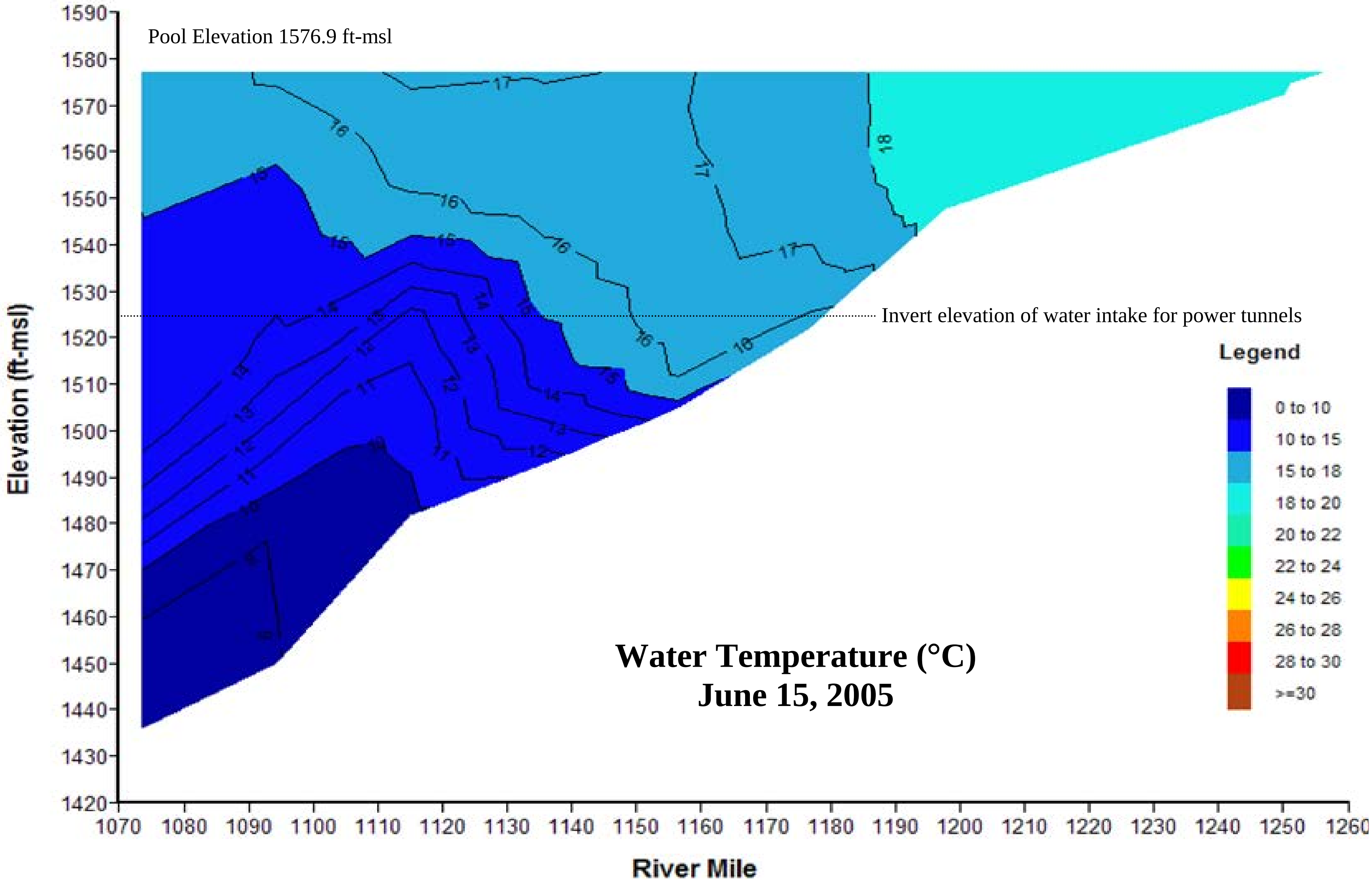

Plate 1. Longitudinal water temperature (°C) contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 15, 2005.

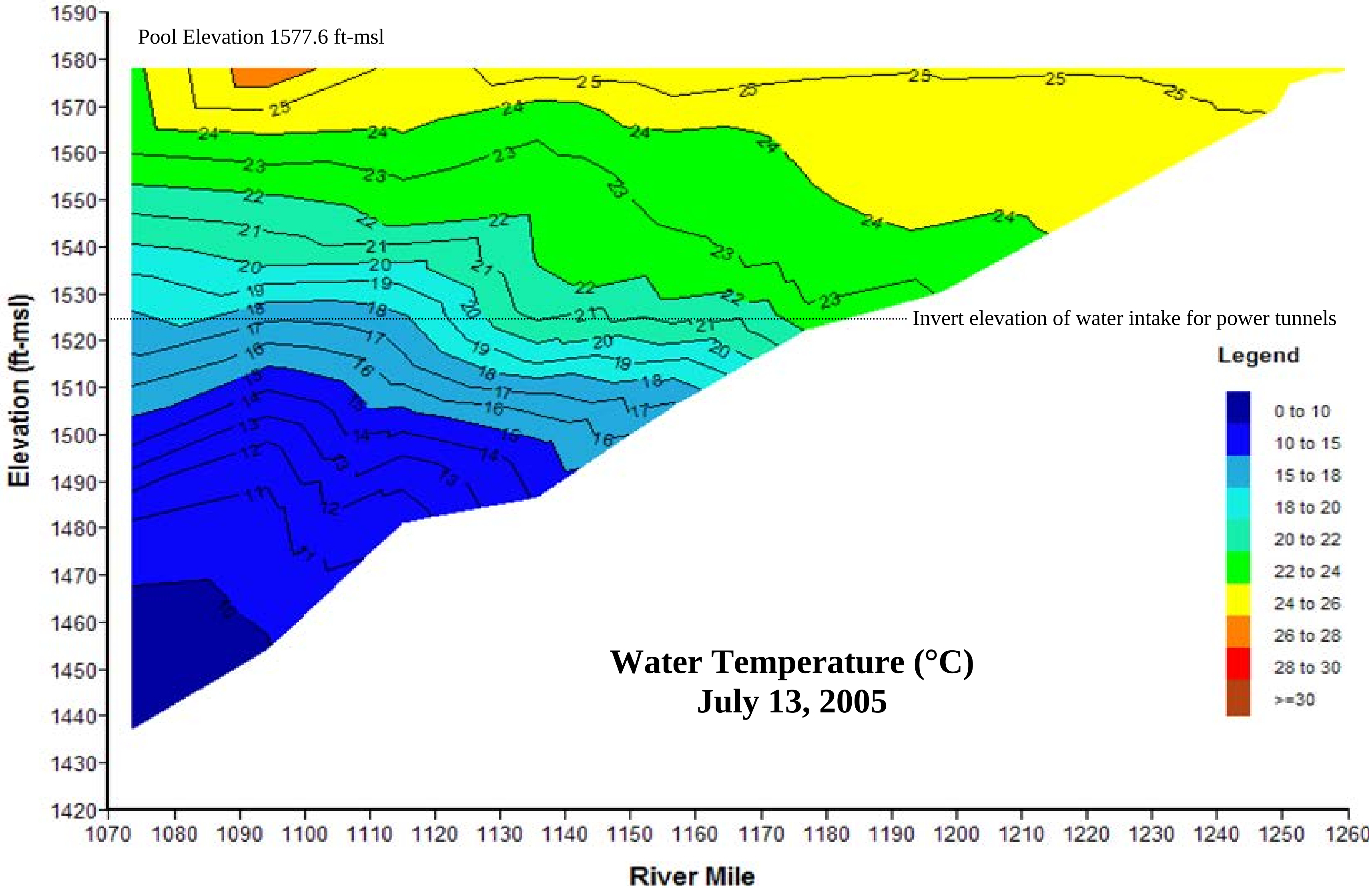

Plate 2. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 13, 2005.

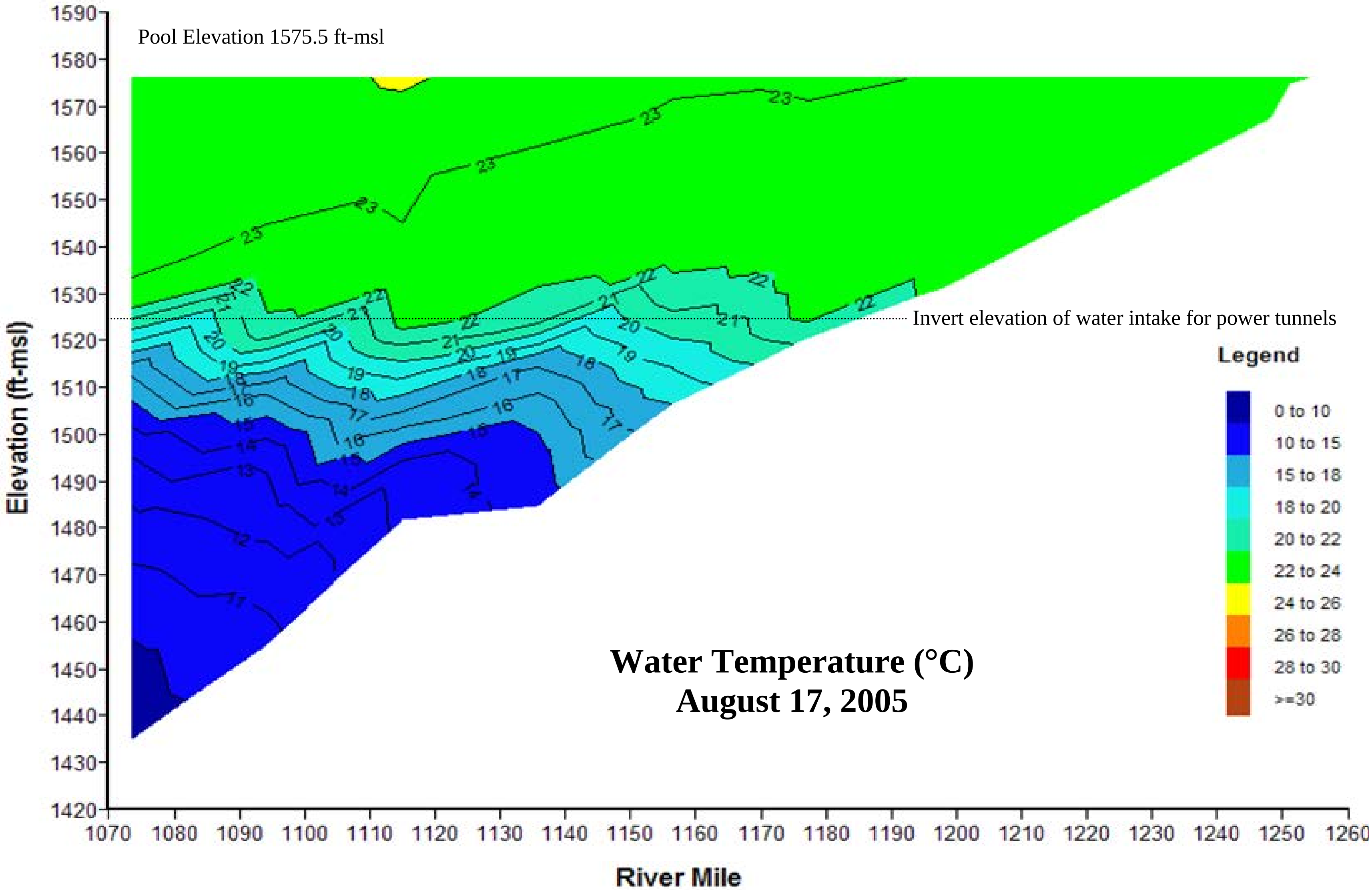

Plate 3. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 17, 2005.

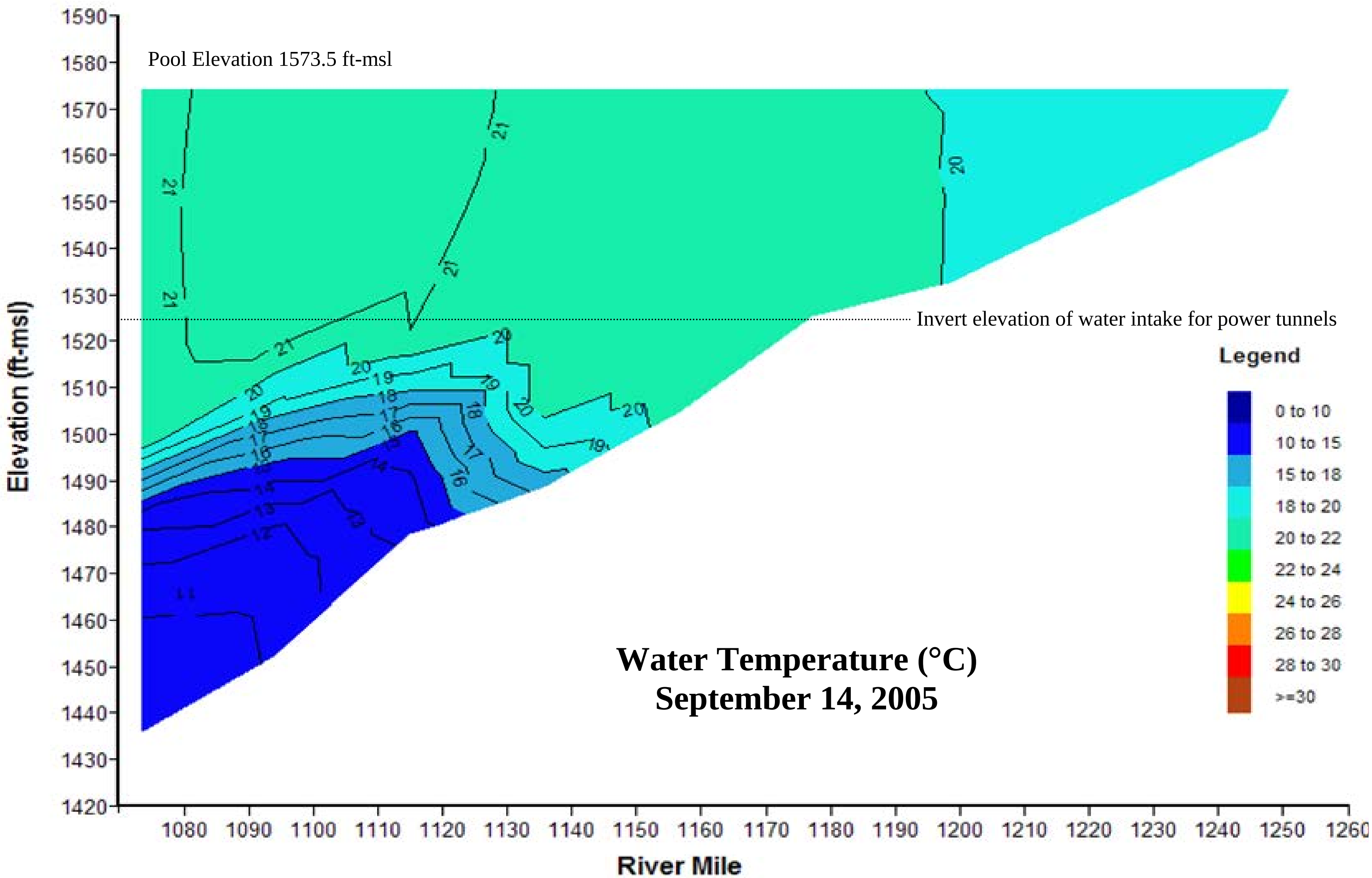

Plate 4. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 14, 2005.

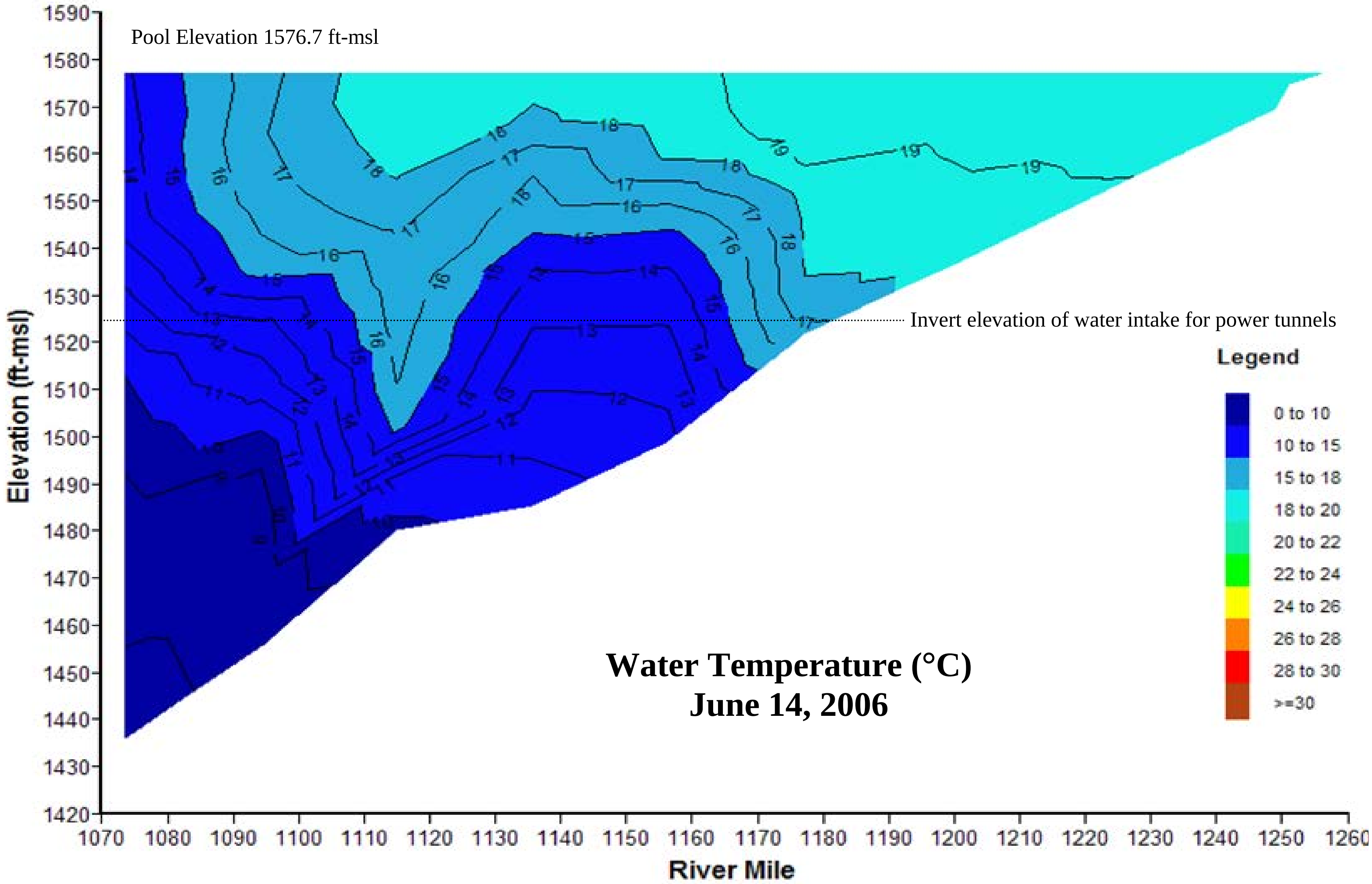

Plate 5. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 14, 2006.

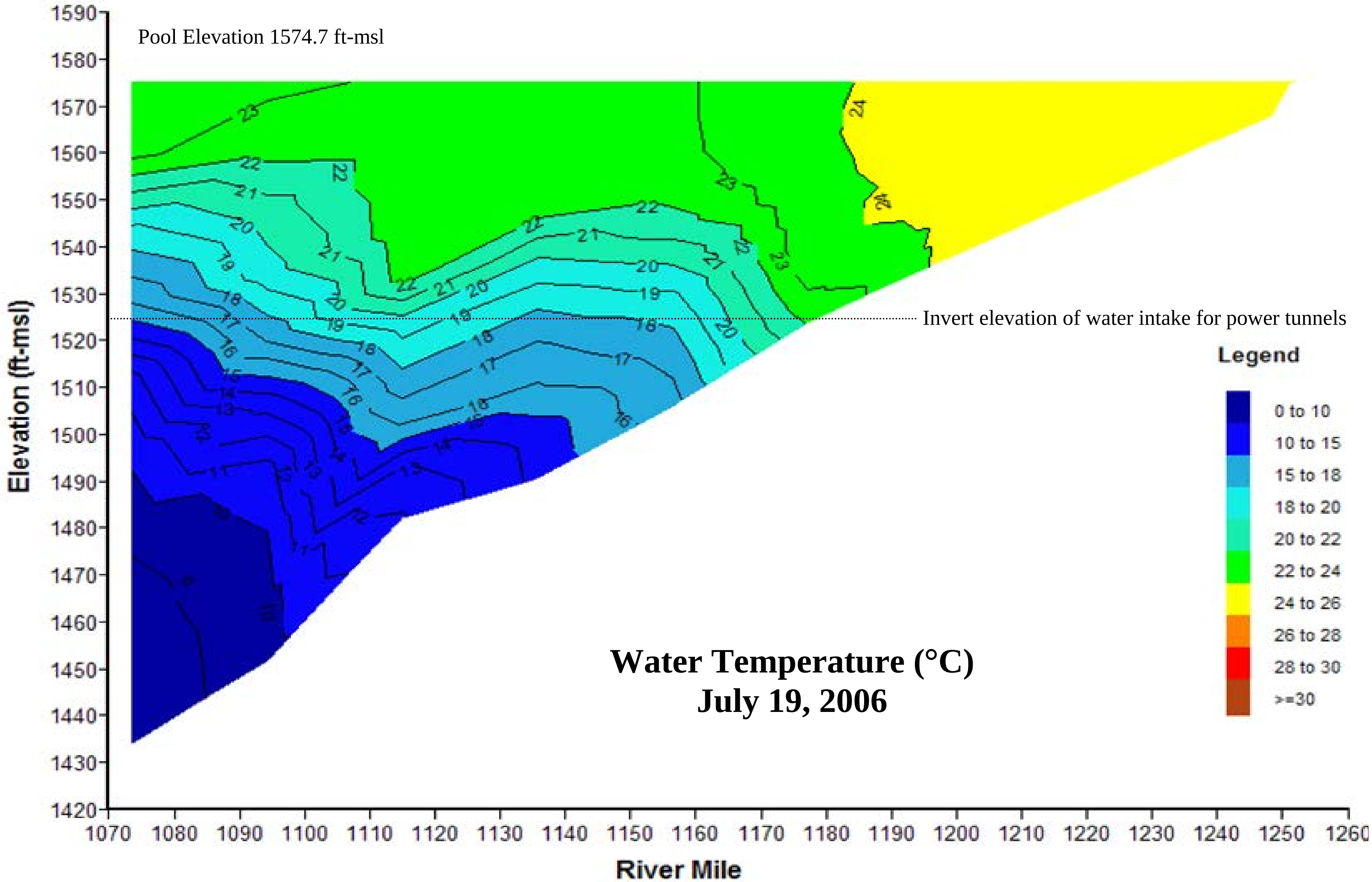

Plate 6. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 19, 2006.

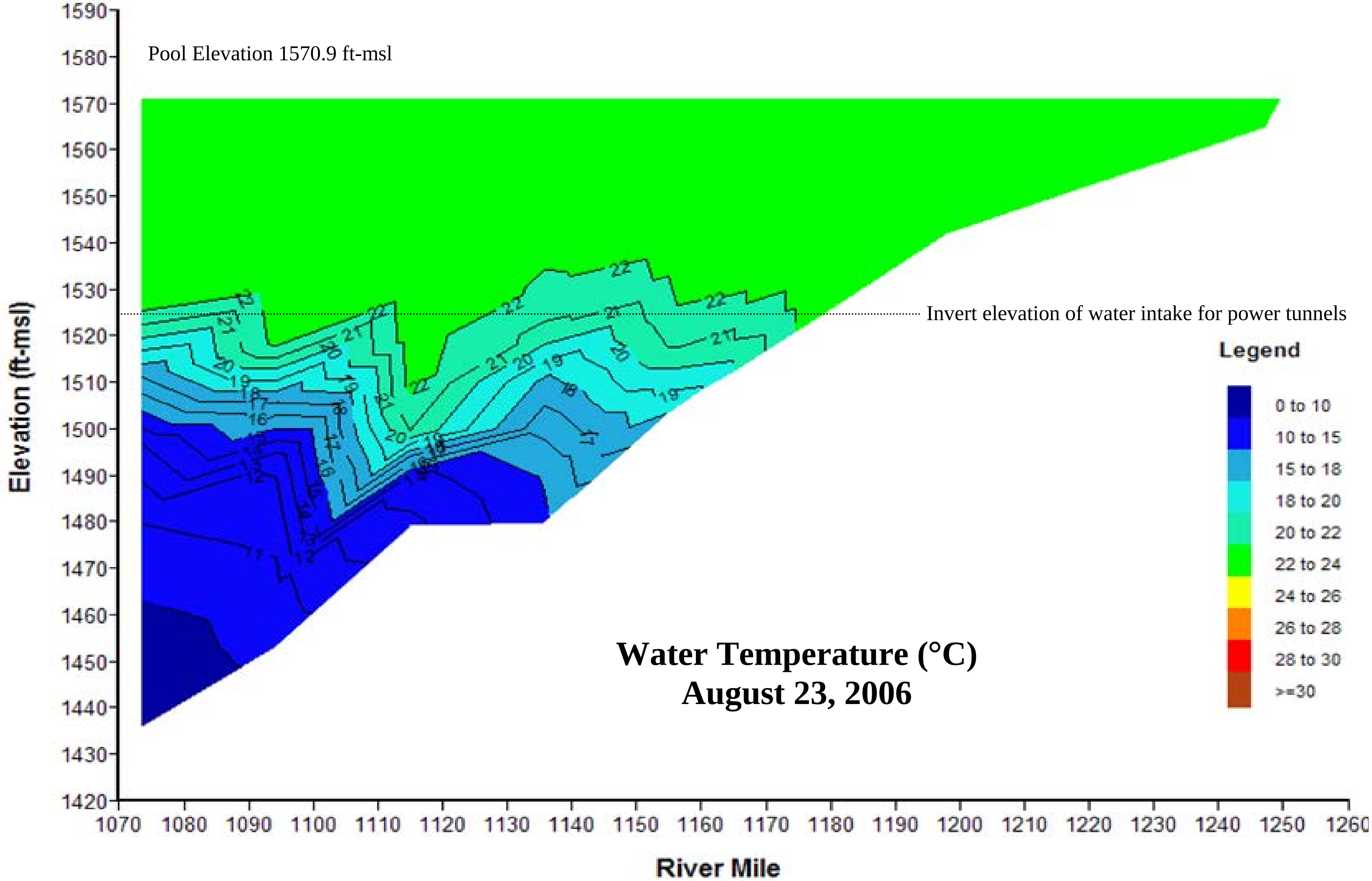

Plate 7. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 23, 2006.

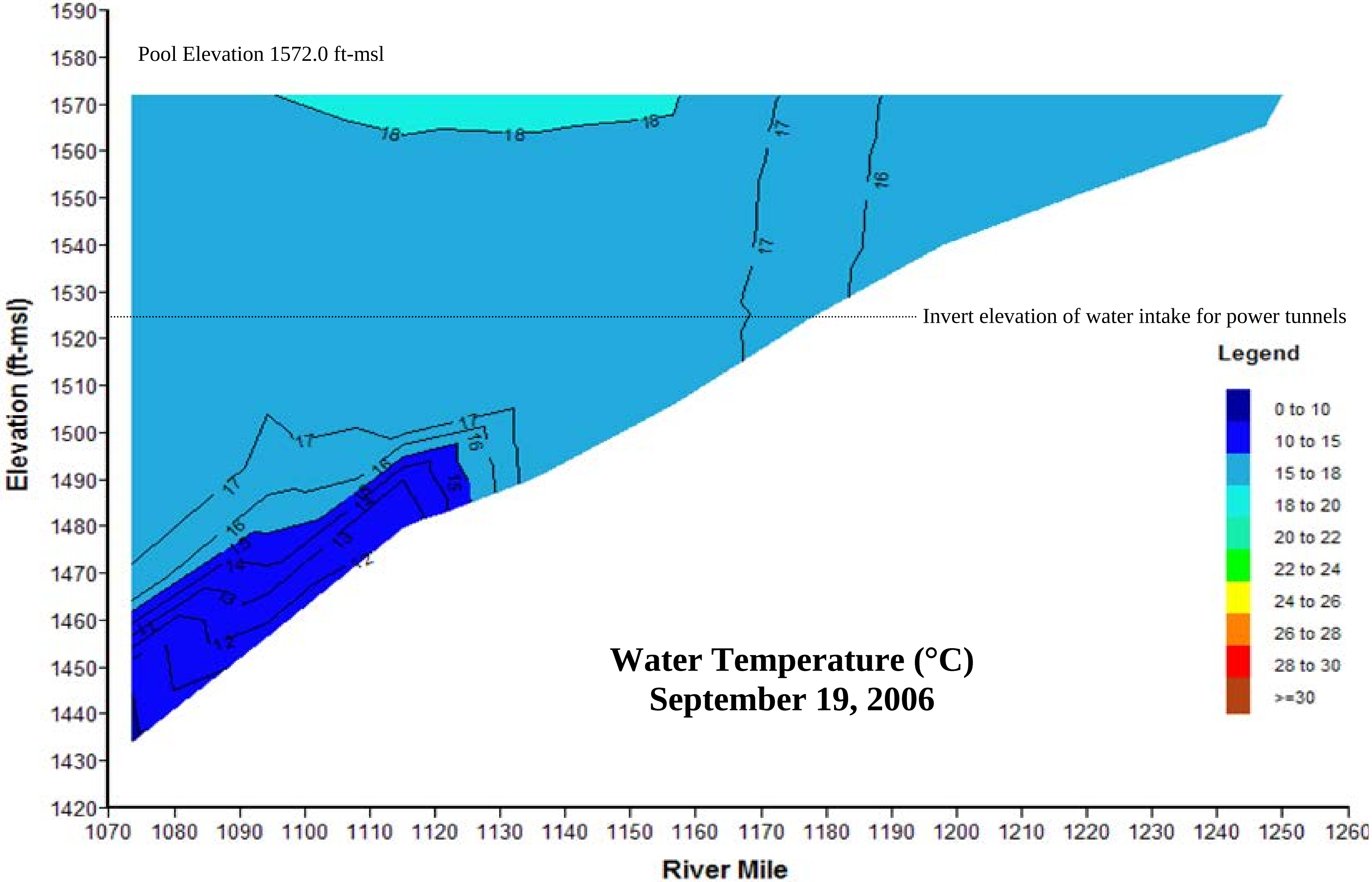

Plate 8. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 19, 2006.

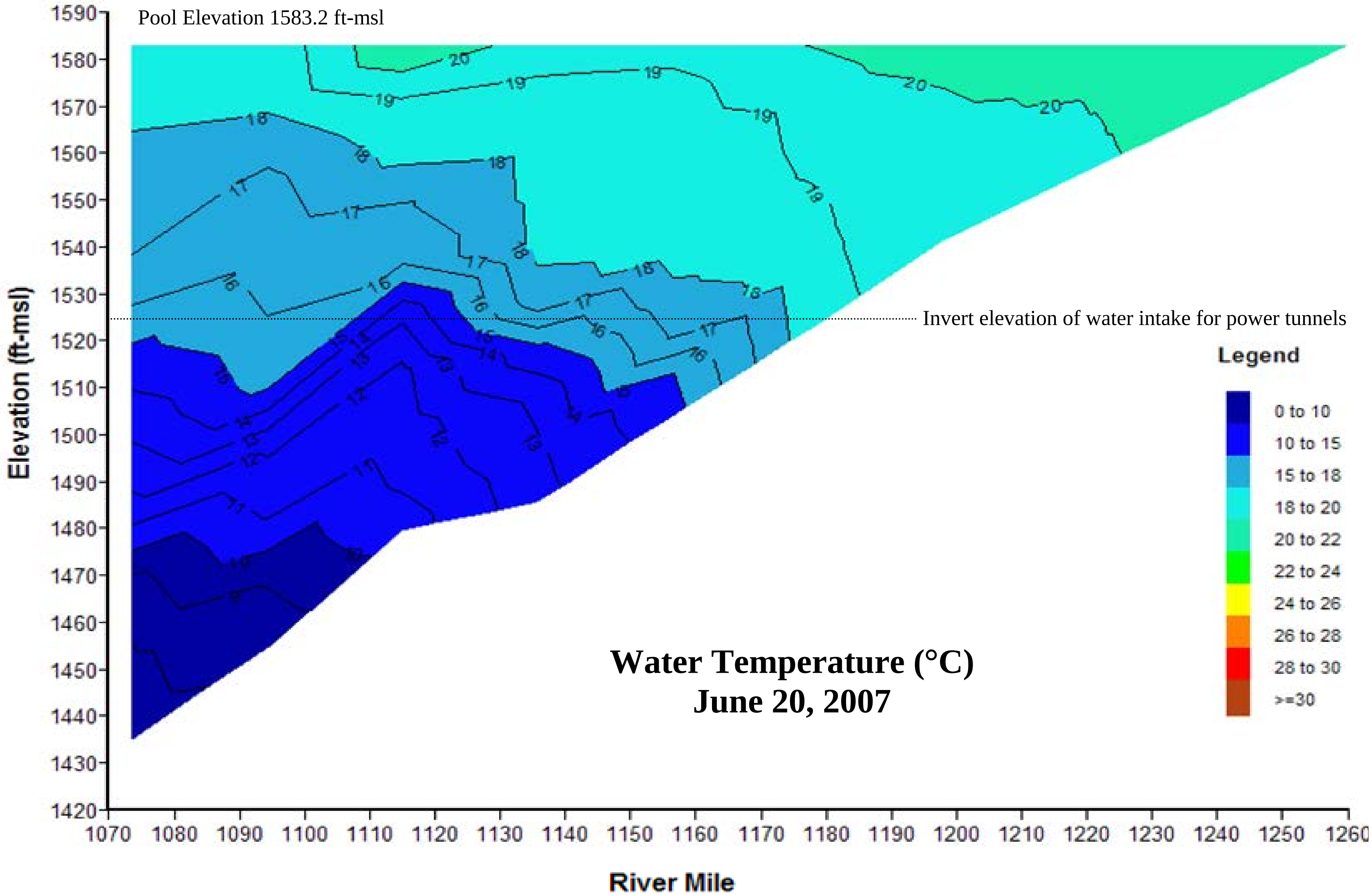

Plate 9. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 20, 2007.

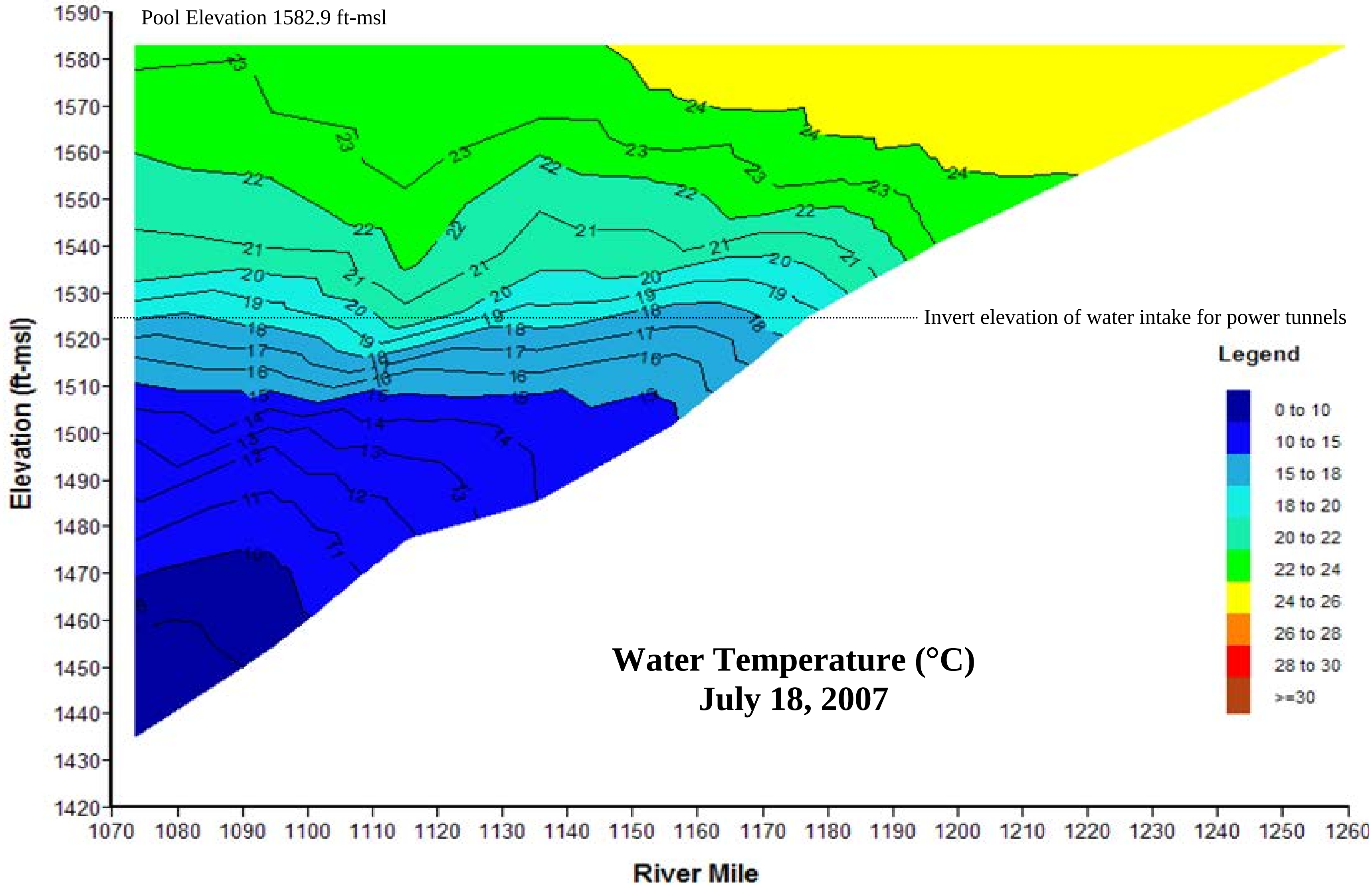

Plate 10. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 18, 2007.

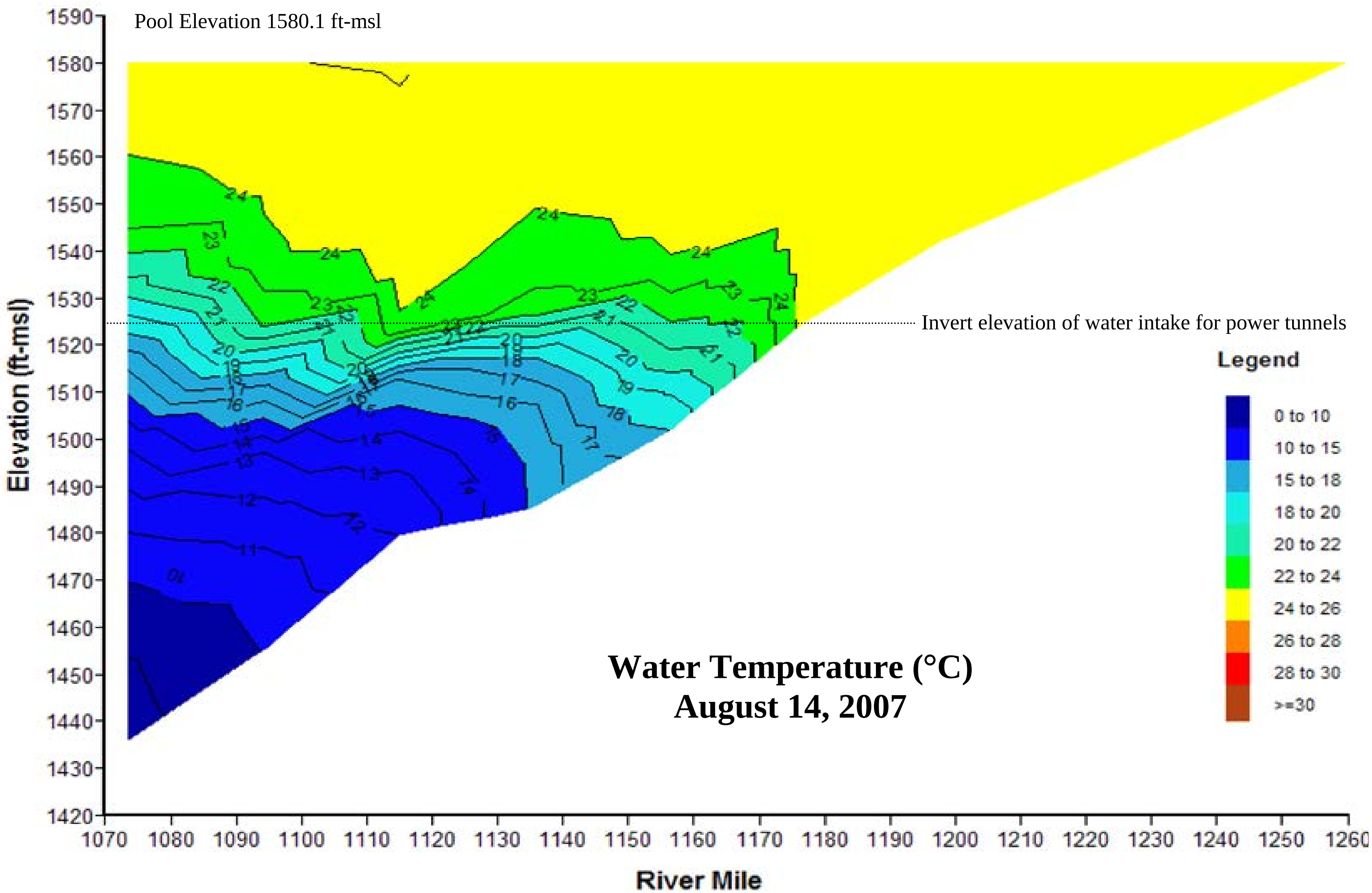

Plate 11. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 14, 2007.

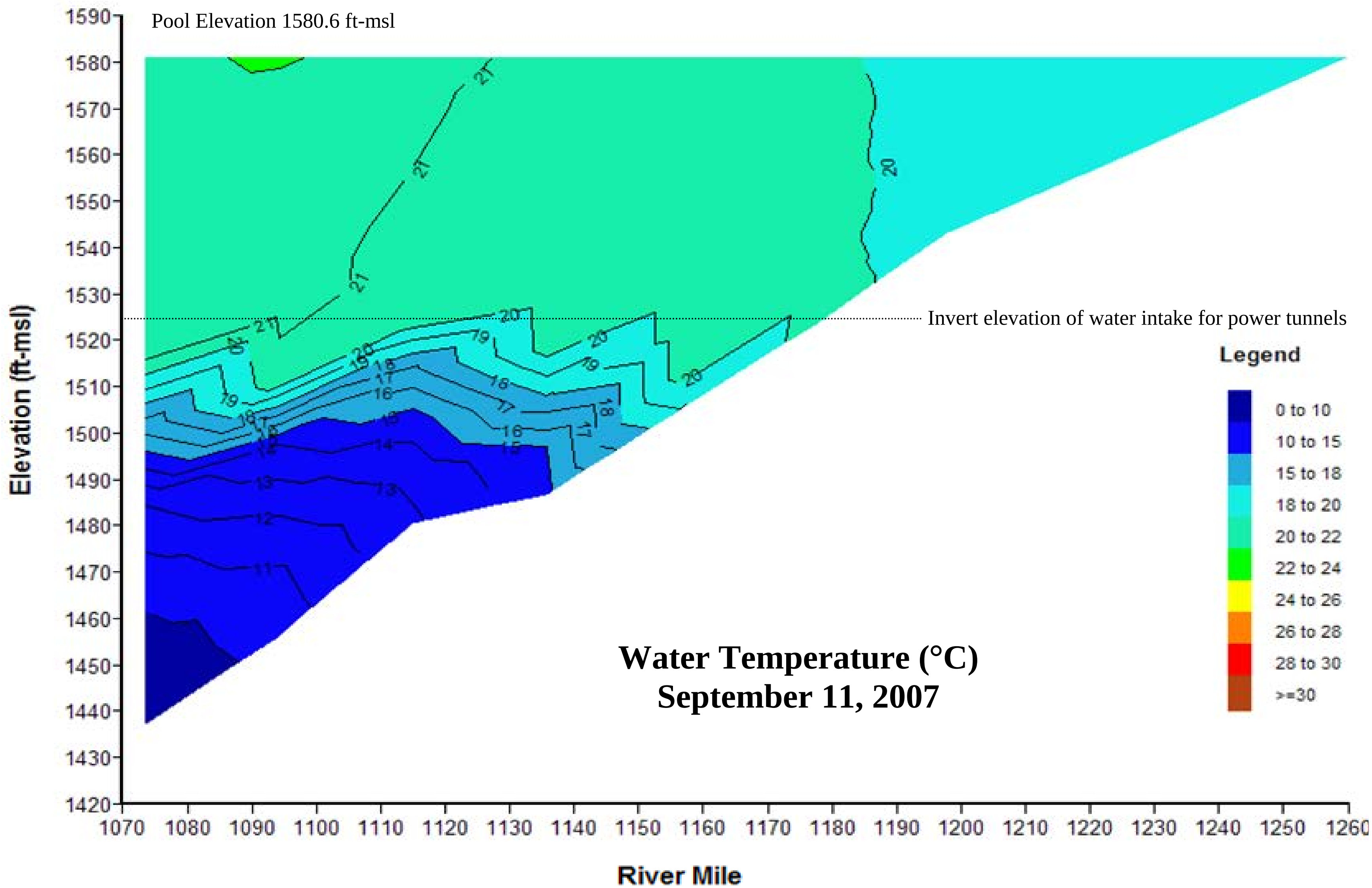

Plate 12. Longitudinal water temperature contour plot of Oahe Reservoir based on depth-profile water temperatures monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 11, 2007.

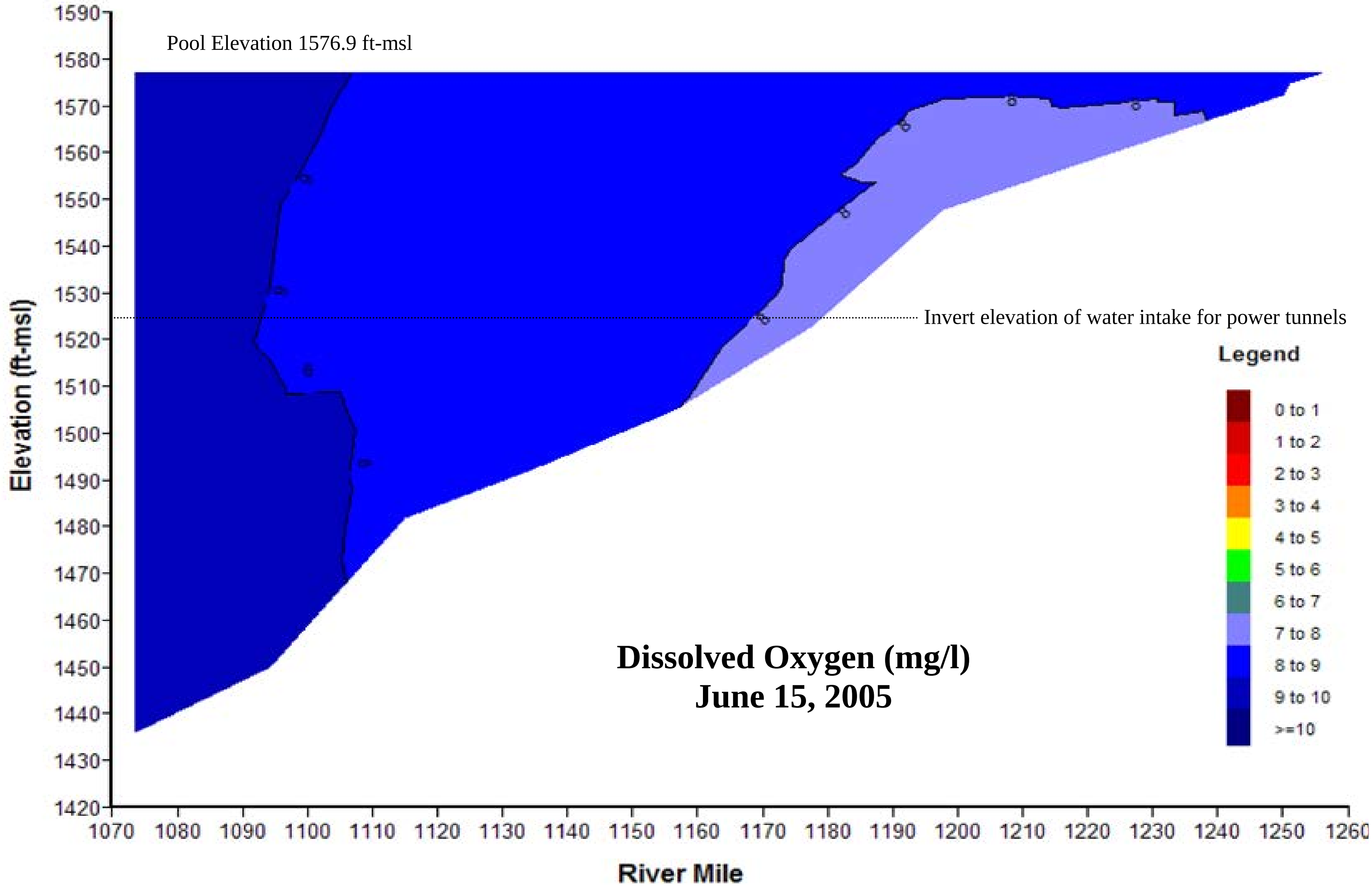

Plate 13. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 15, 2005.

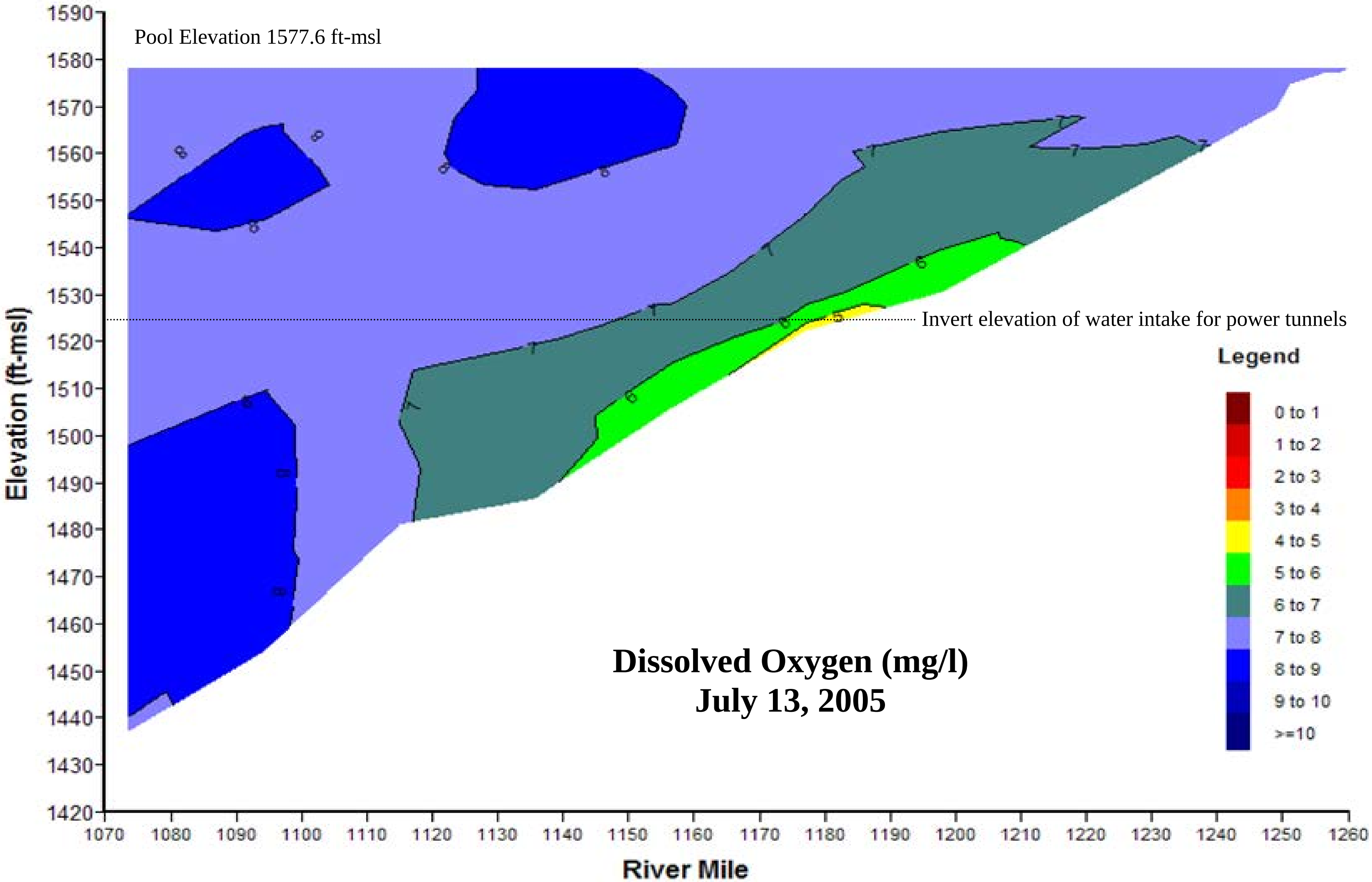

Plate 14. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 13, 2005.

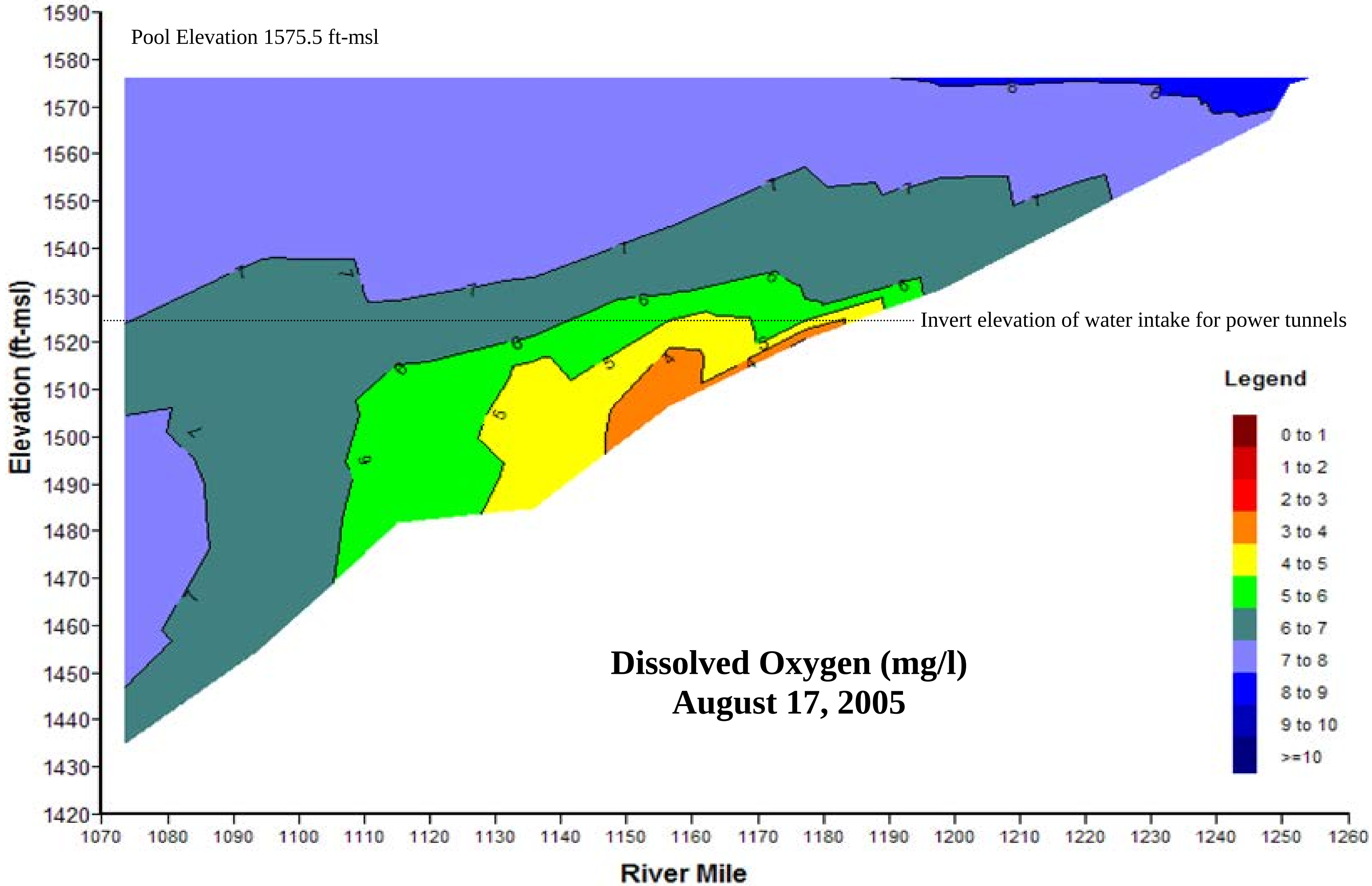

Plate 15. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 17, 2005.

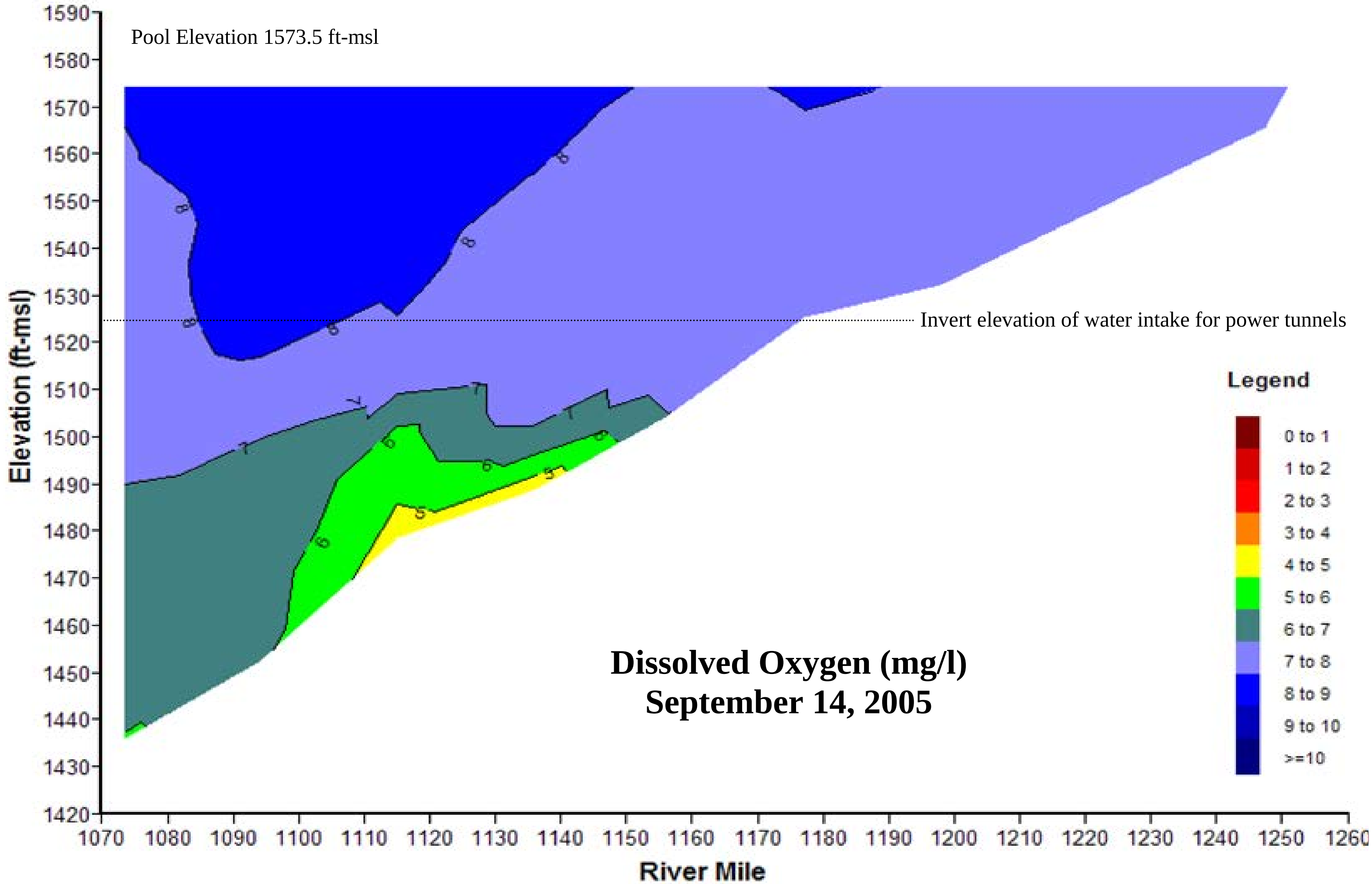

Plate 16. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 14, 2005.

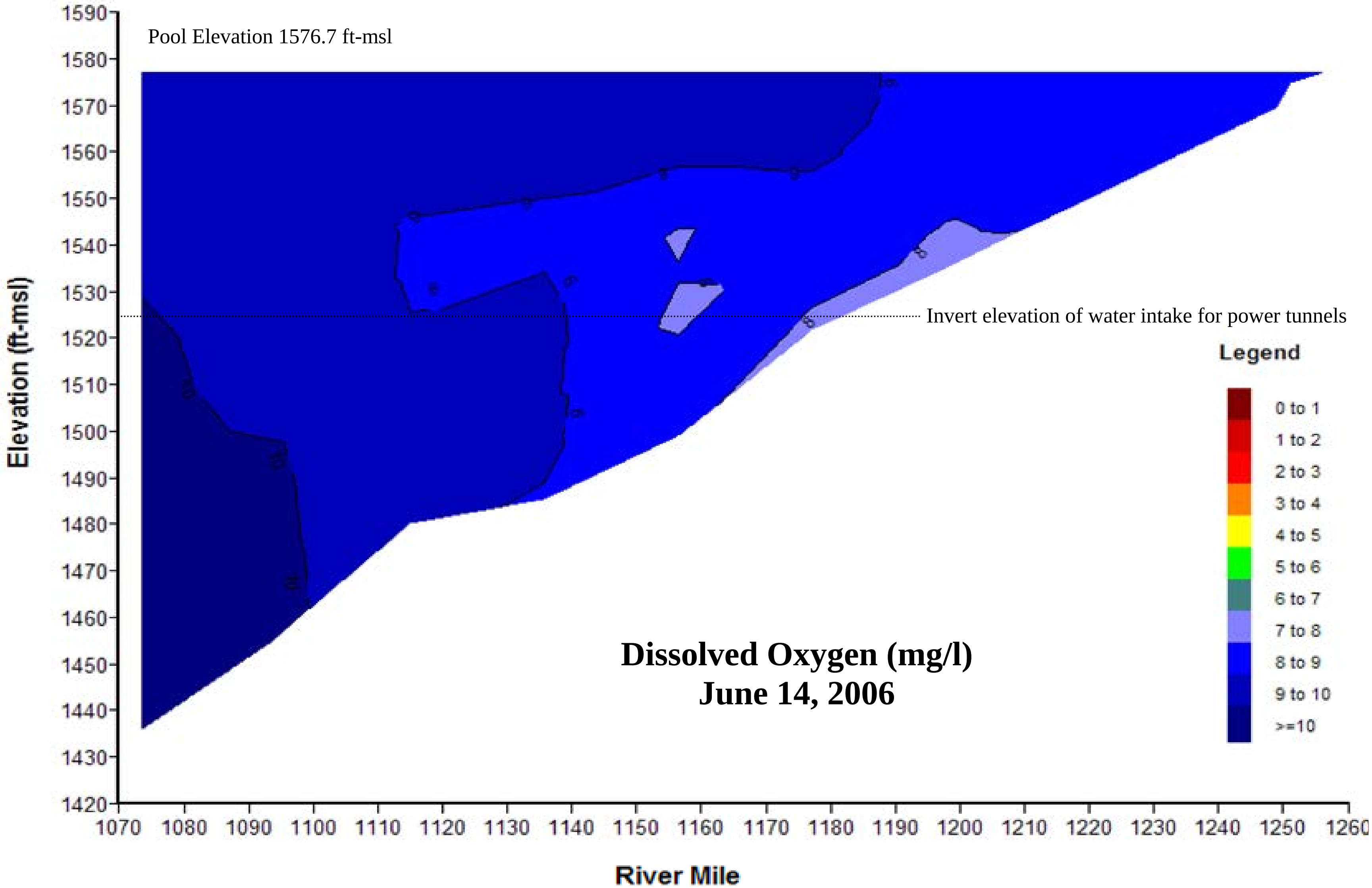

Plate 17. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 14, 2006.

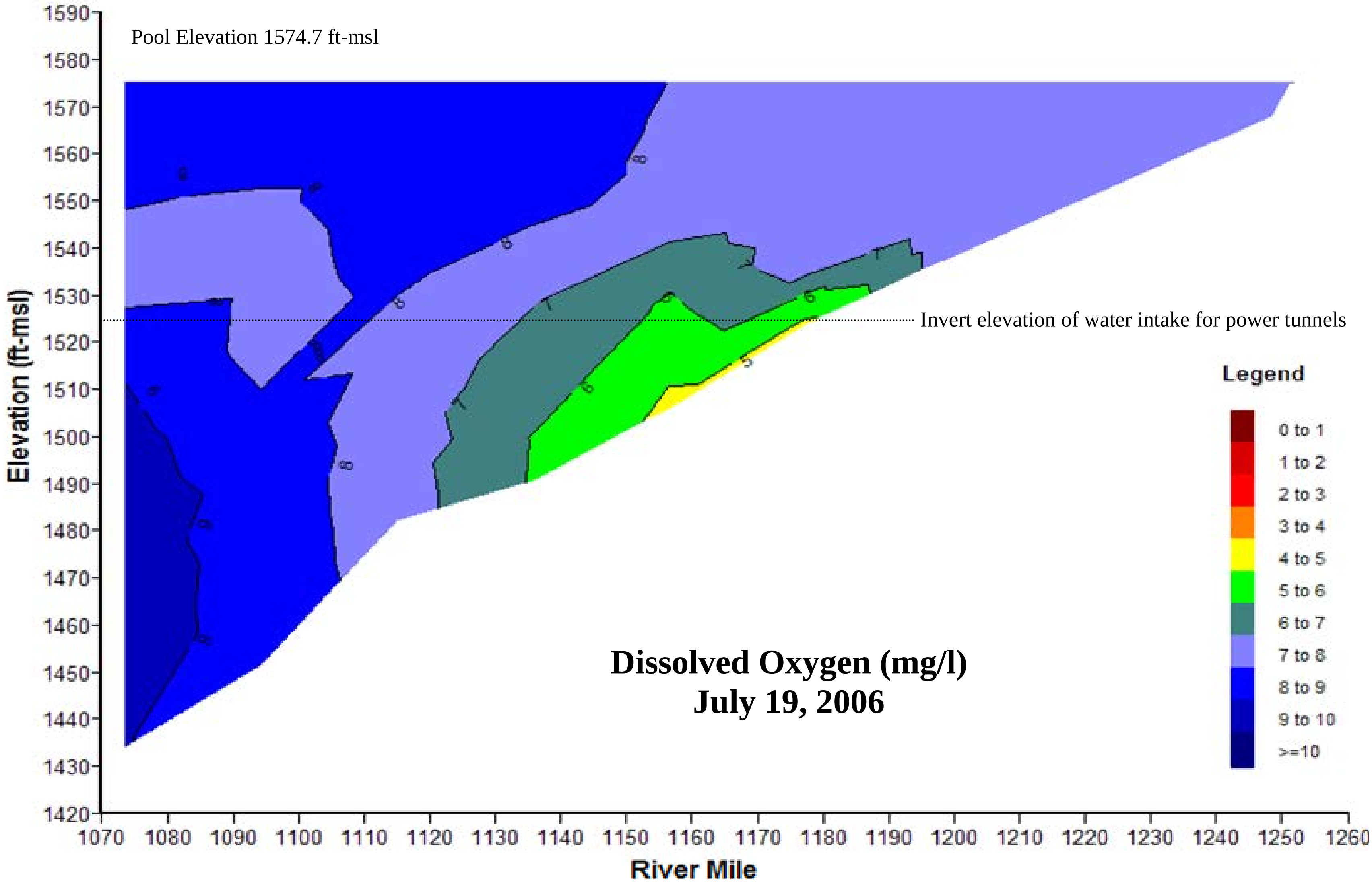

Plate 18. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 19, 2006.

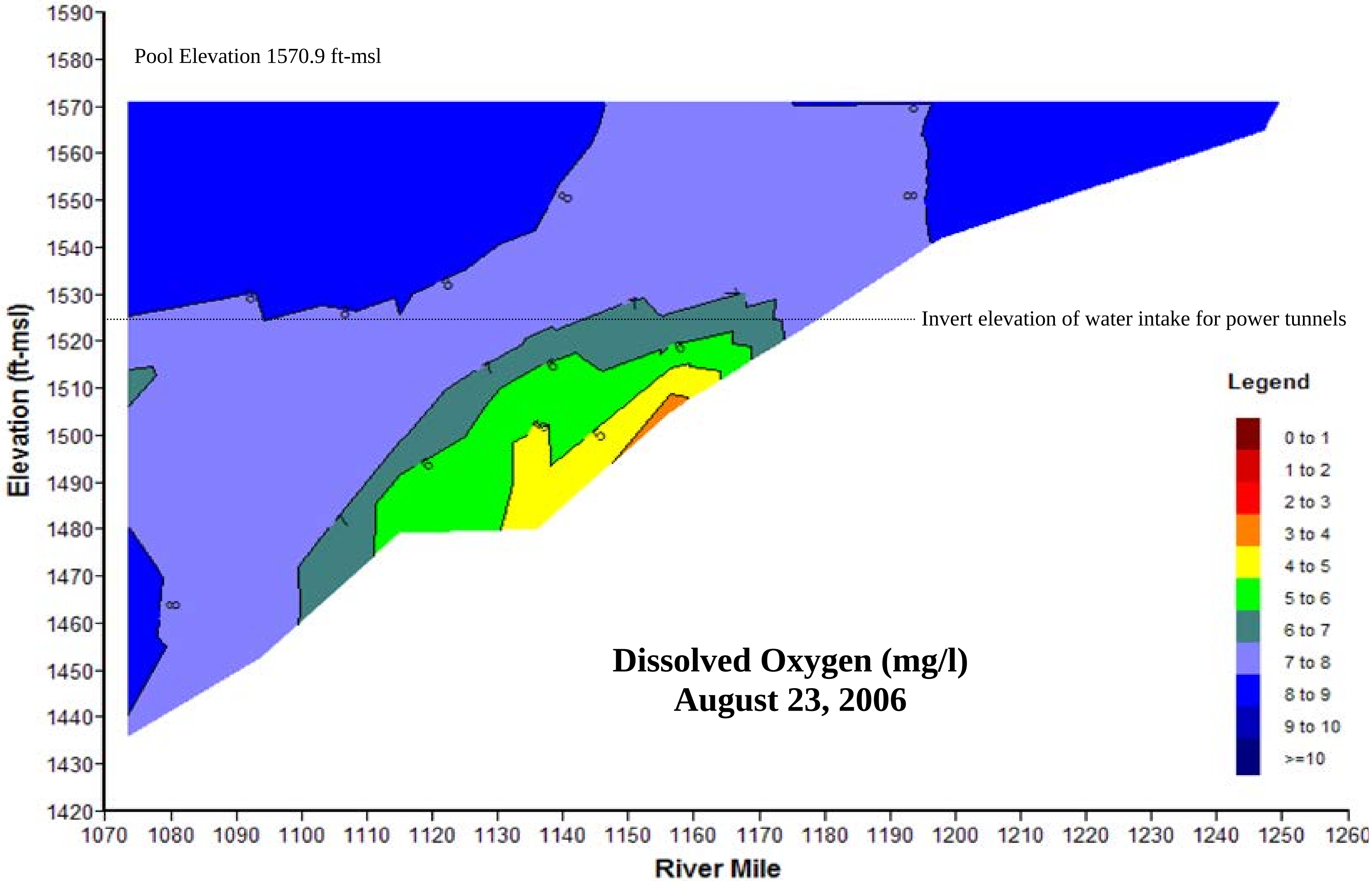

Plate 19. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 23, 2006.

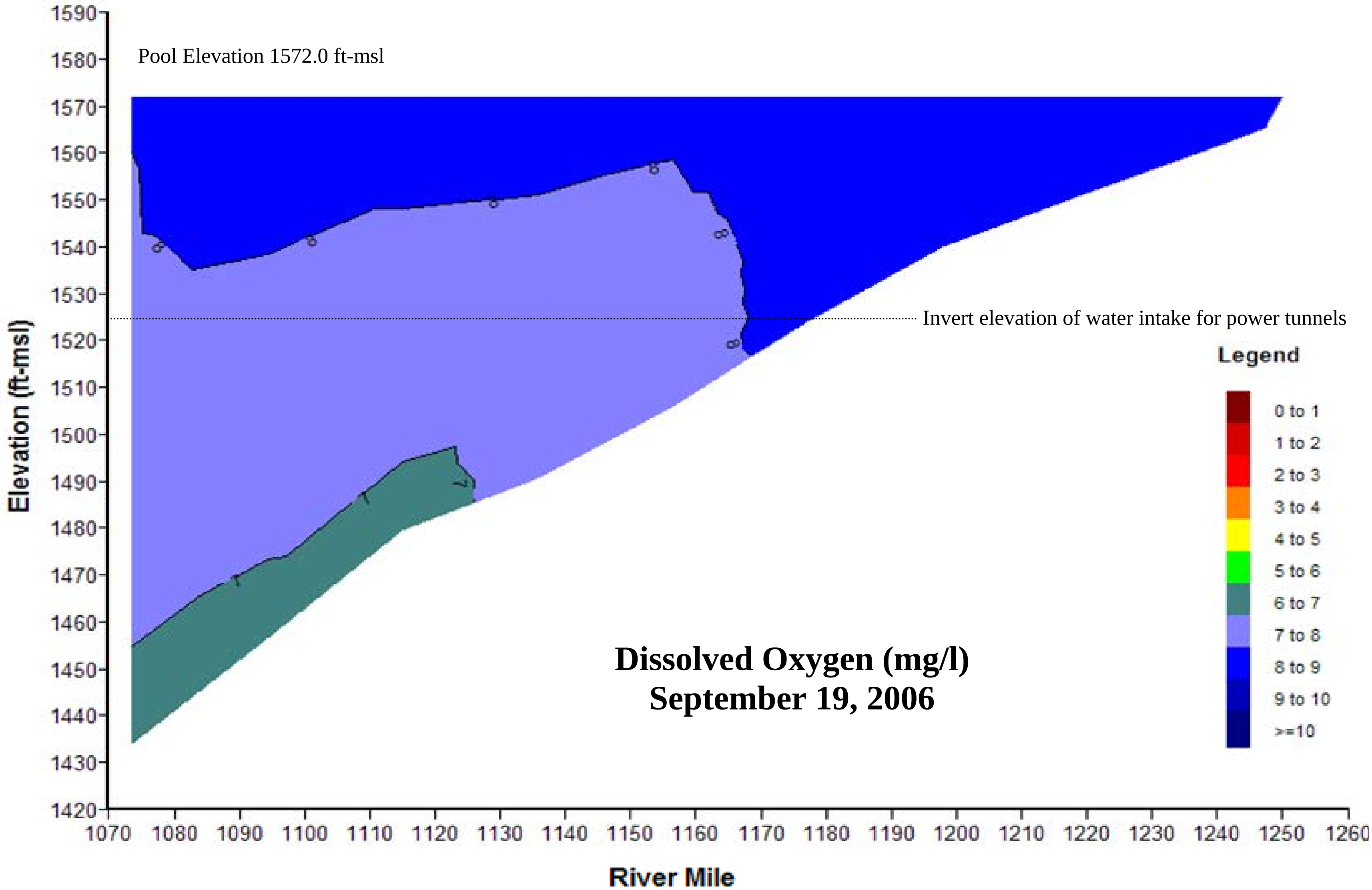

Plate 20. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 19, 2006.

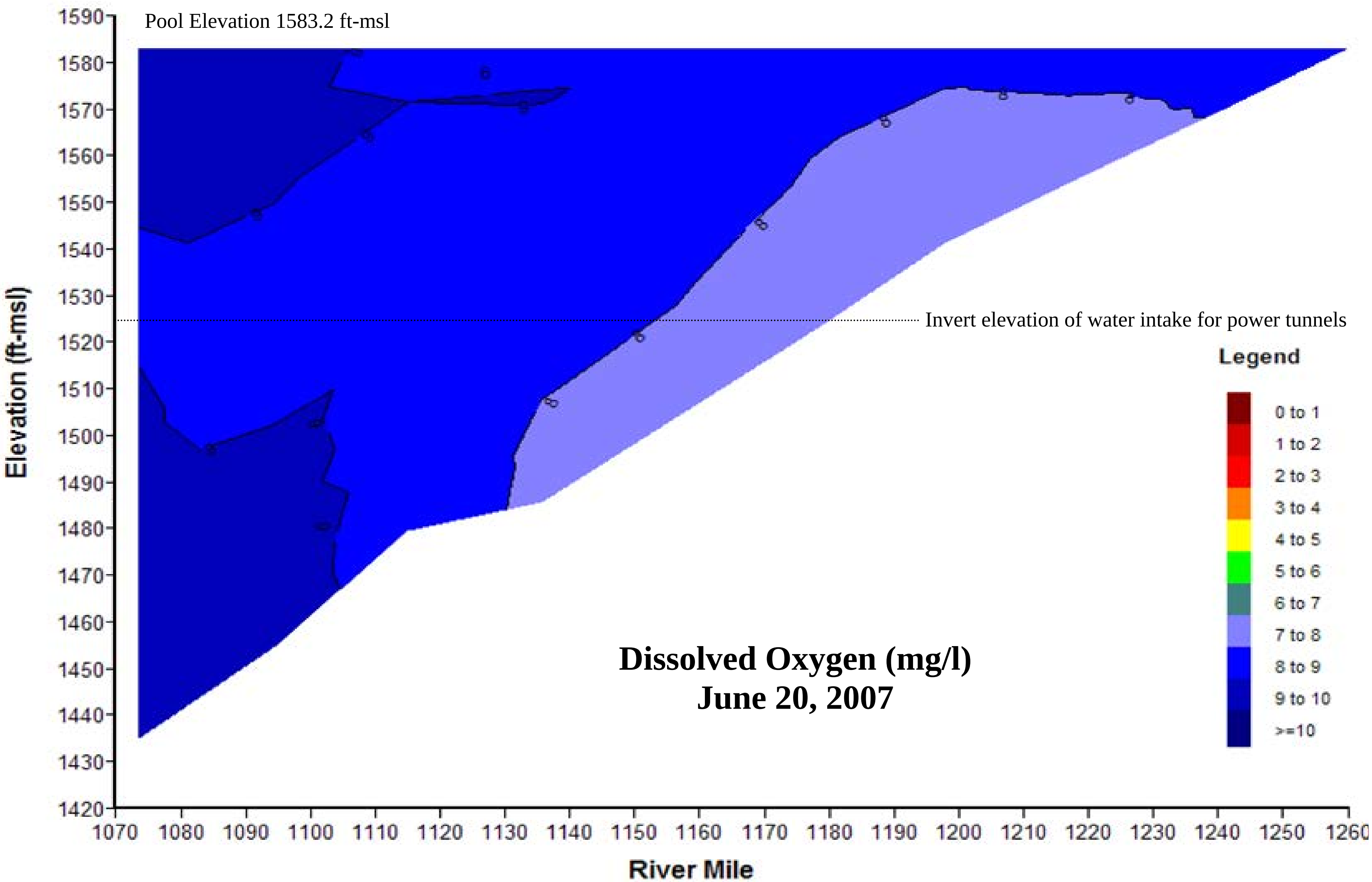

Plate 21. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 20, 2007.

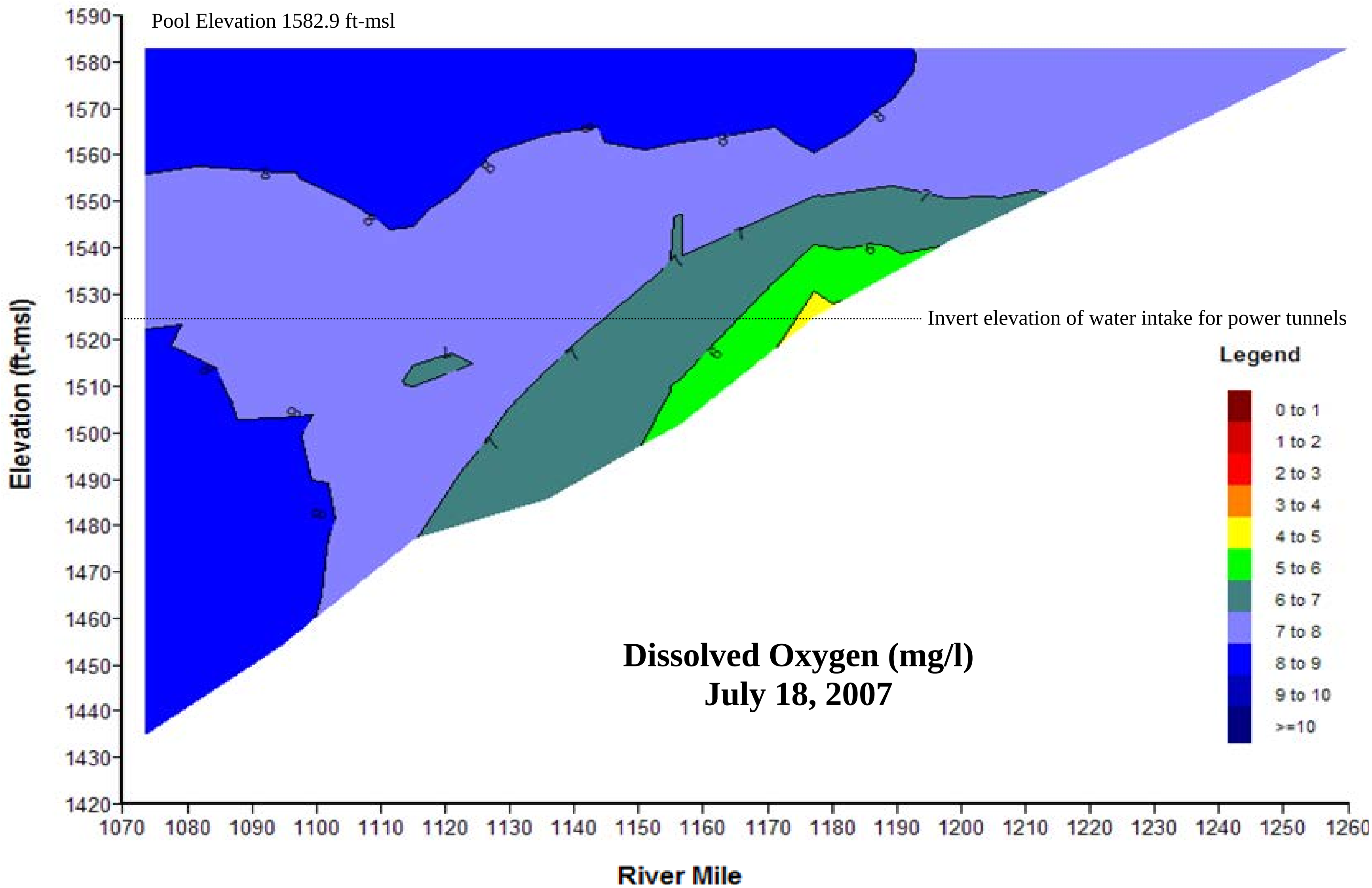

Plate 22. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 18, 2007.

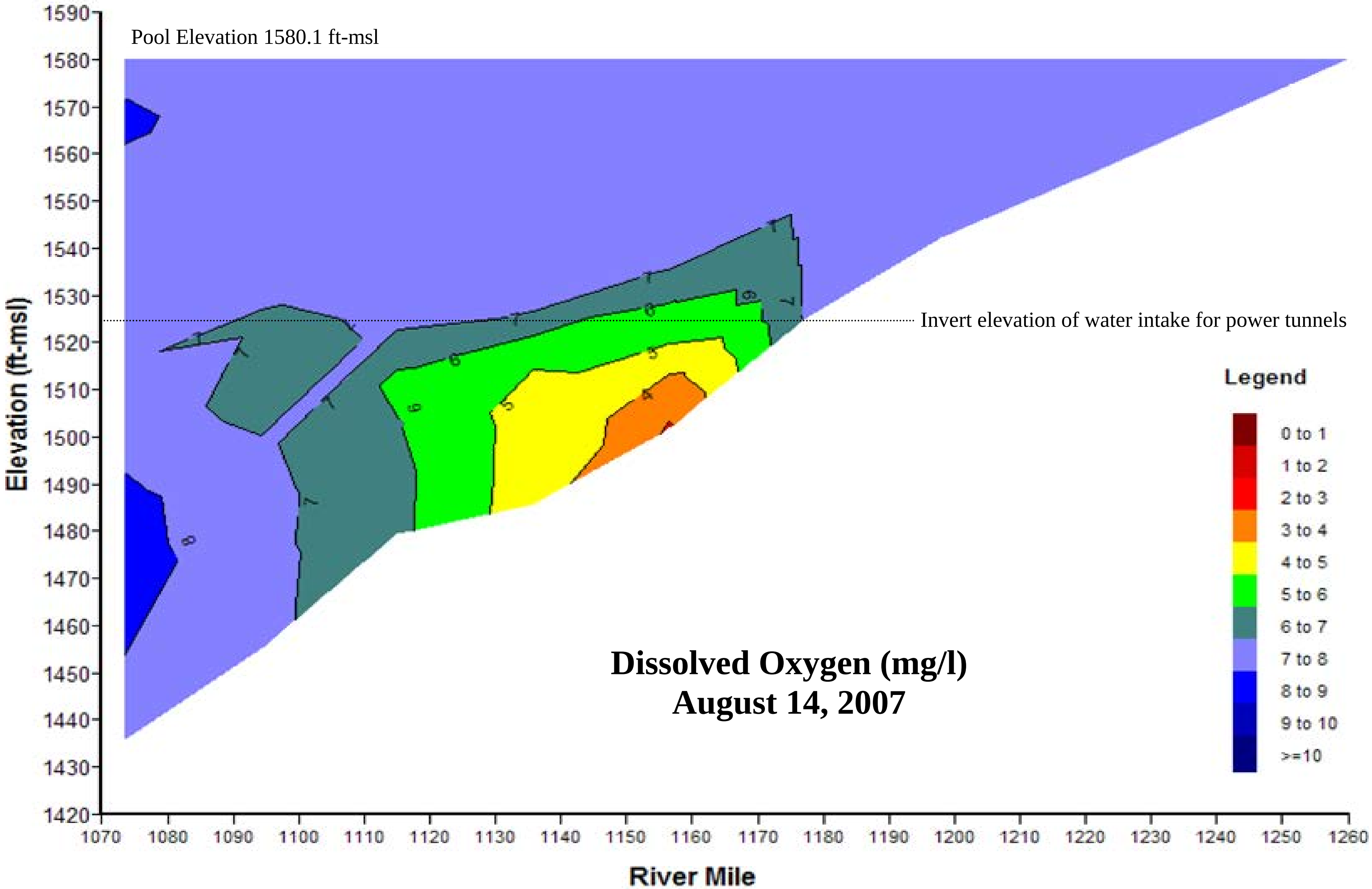

Plate 23. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 14, 2007.

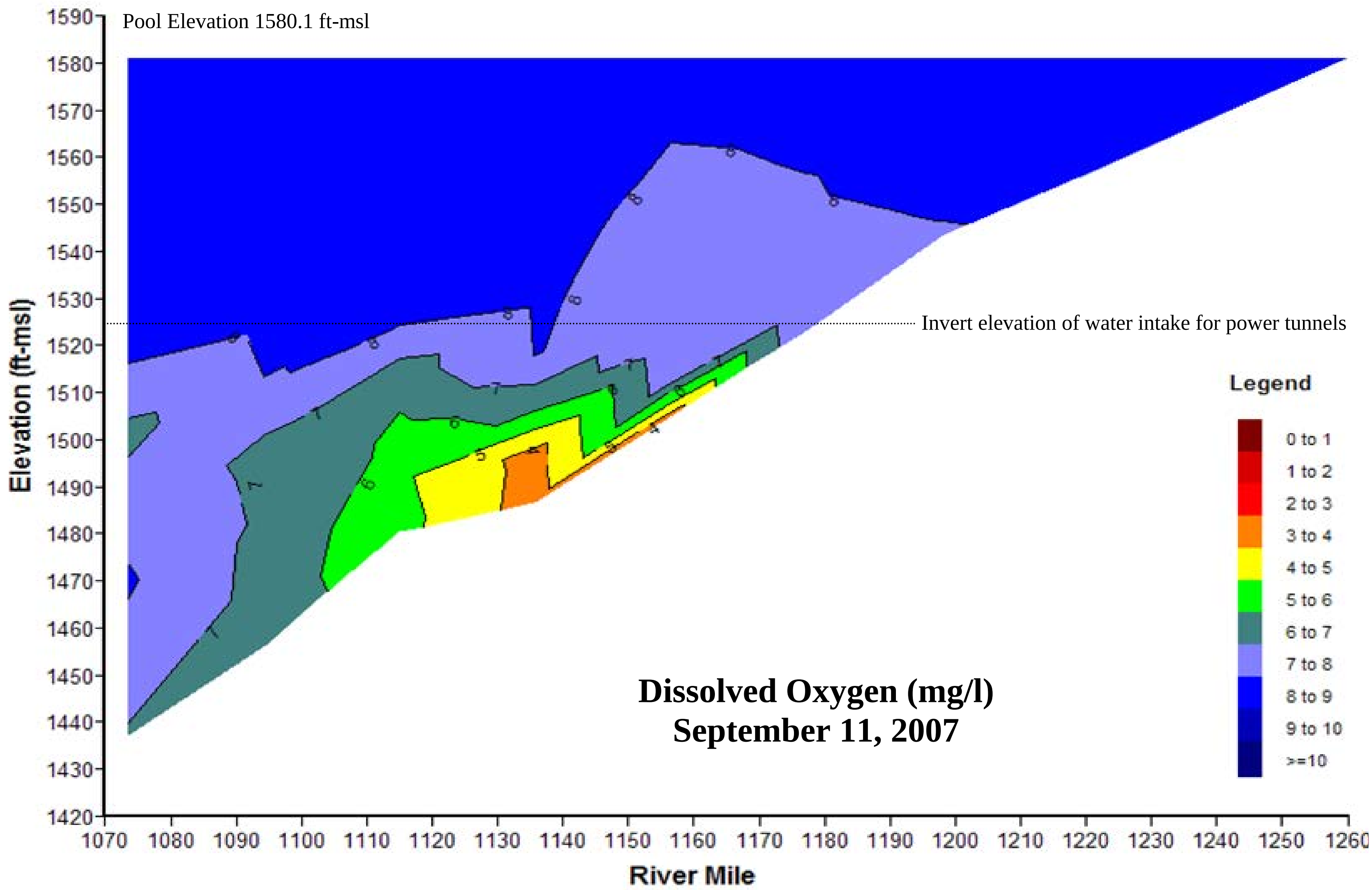

Plate 24. Longitudinal dissolved oxygen contour plot of Oahe Reservoir based on depth-profile dissolved oxygen concentrations monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 11, 2007.

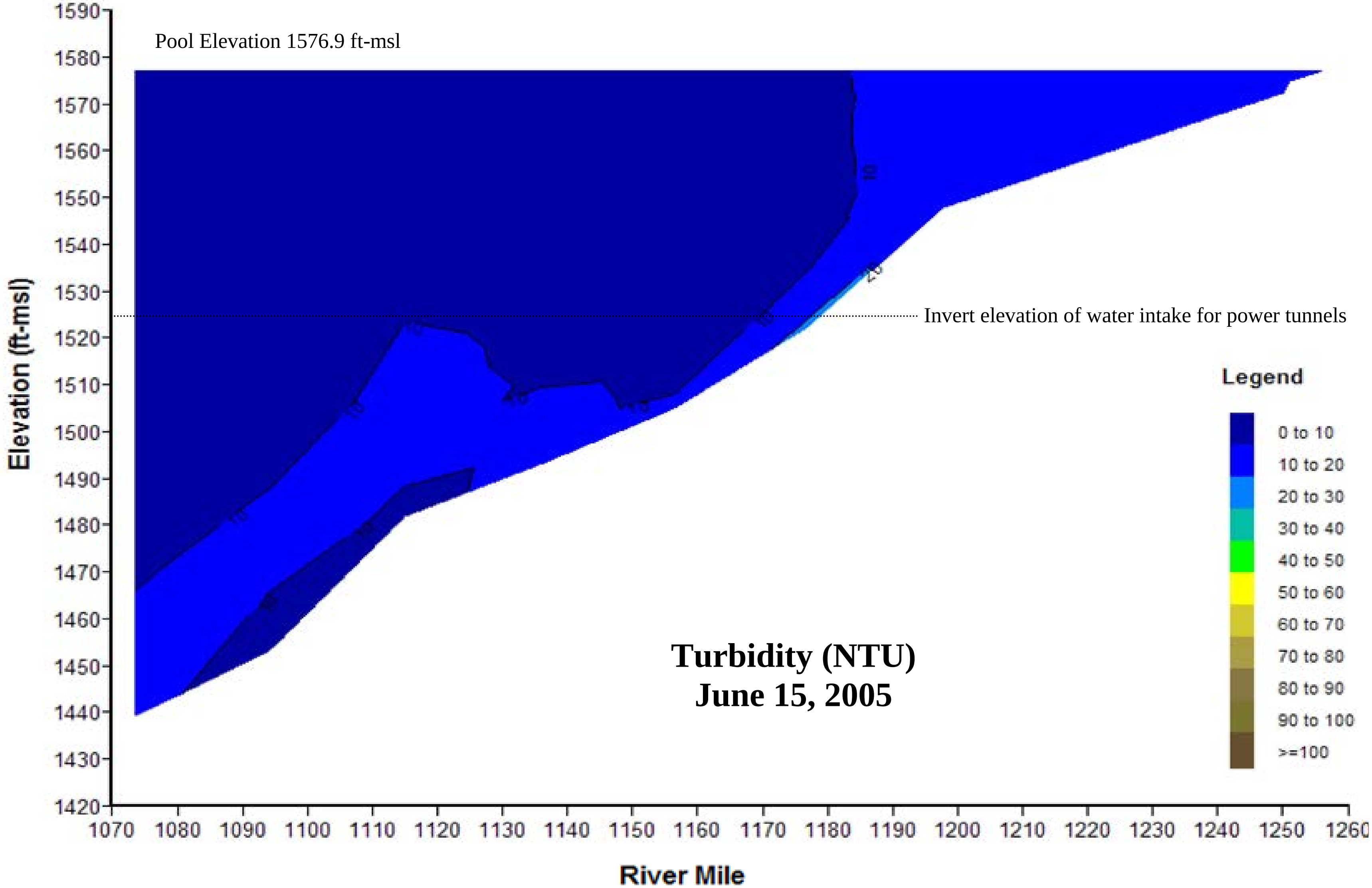

Plate 25. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 15, 2005.

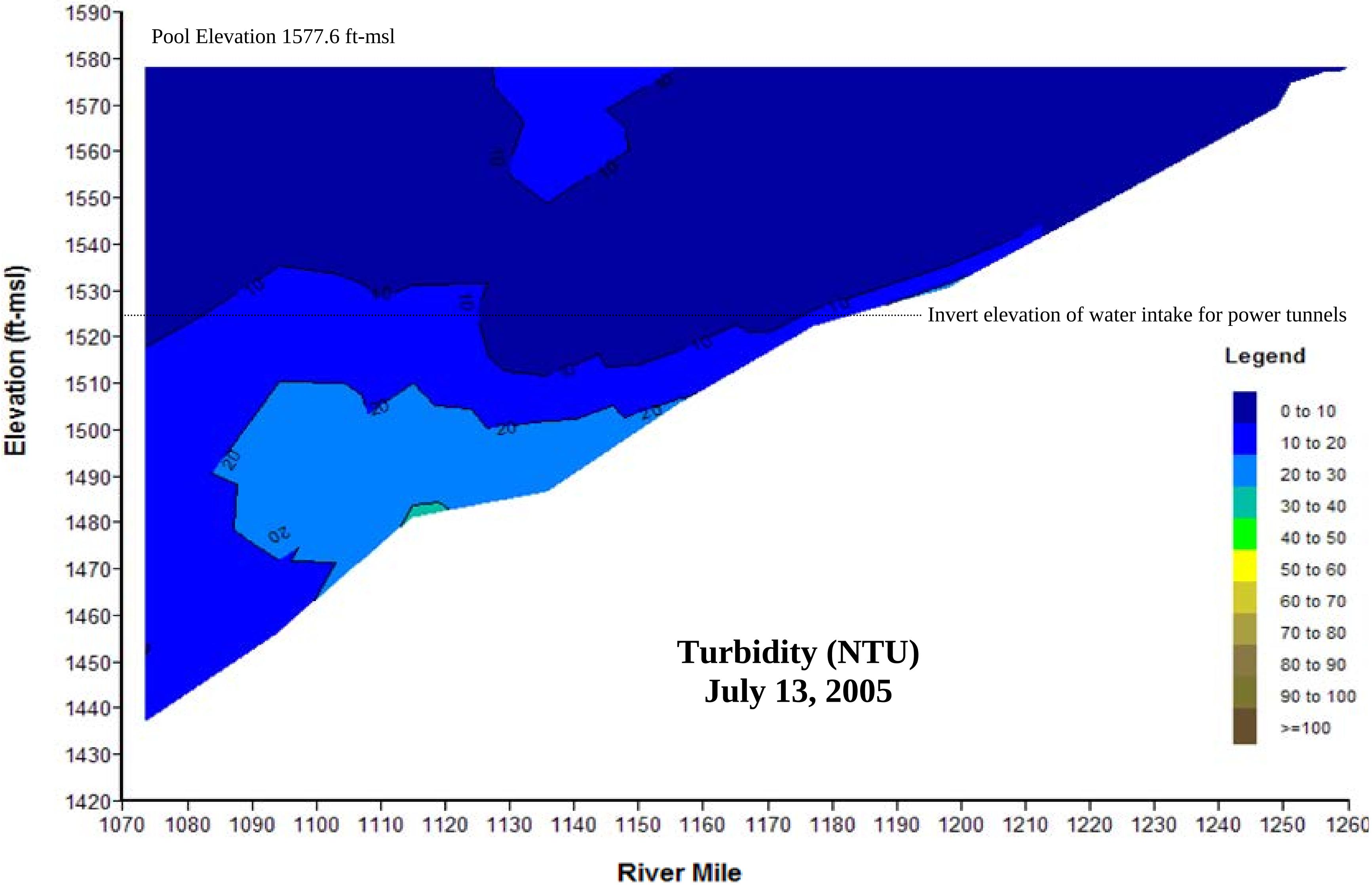

Plate 26. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 13, 2005.

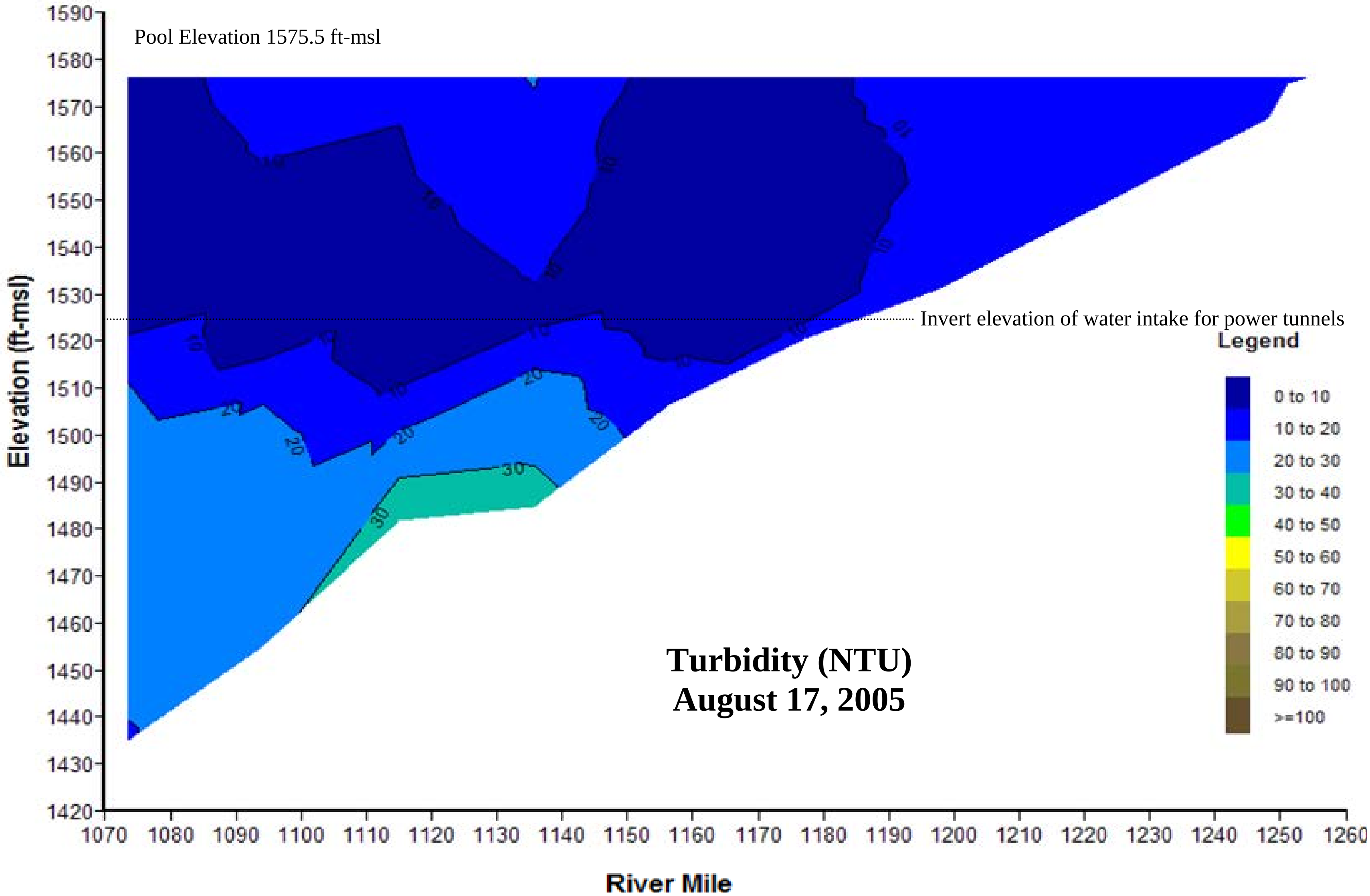

Plate 27. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 17, 2005.

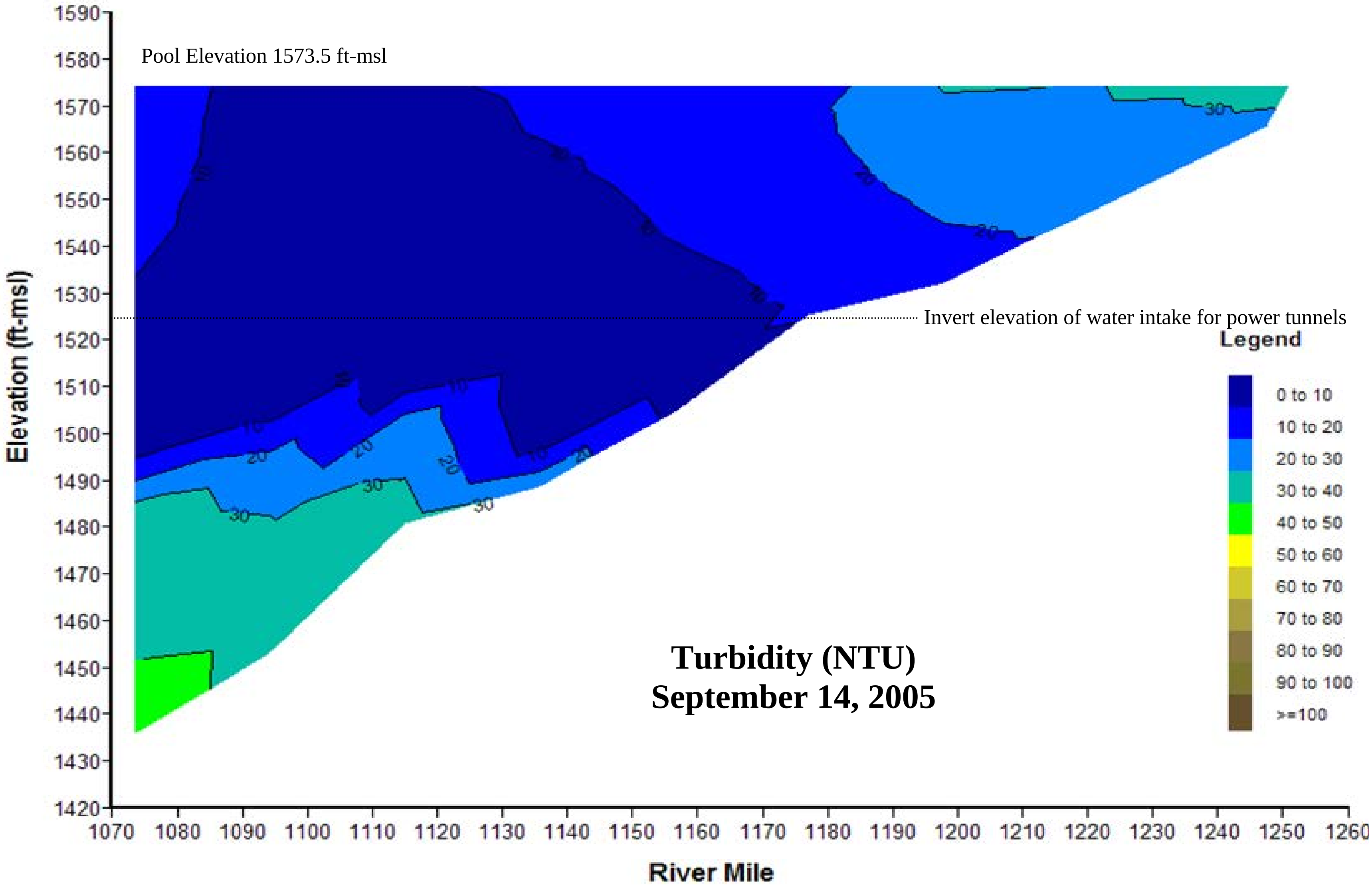

Plate 28. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 14, 2005.

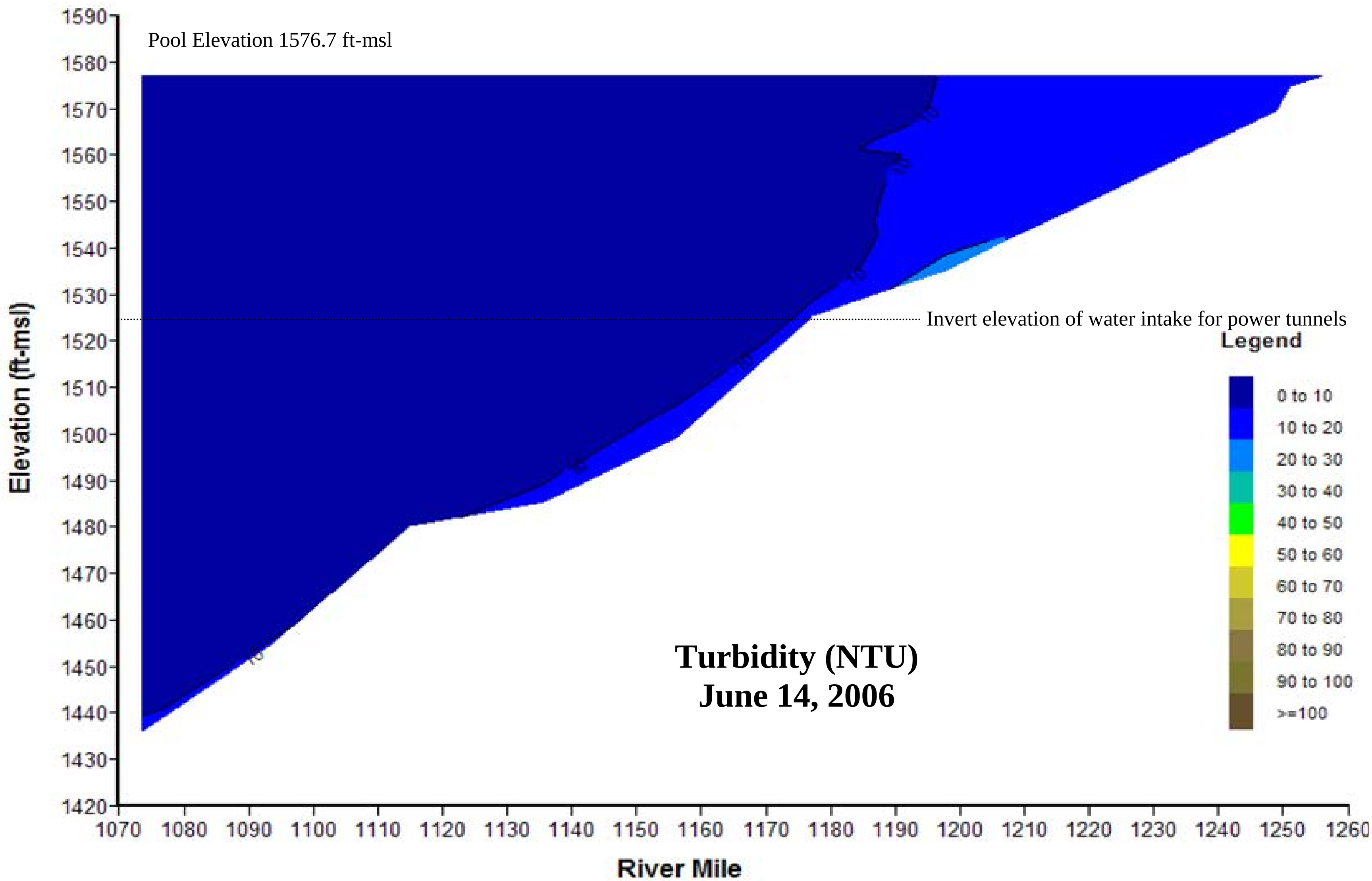

Plate 29. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 14, 2006.

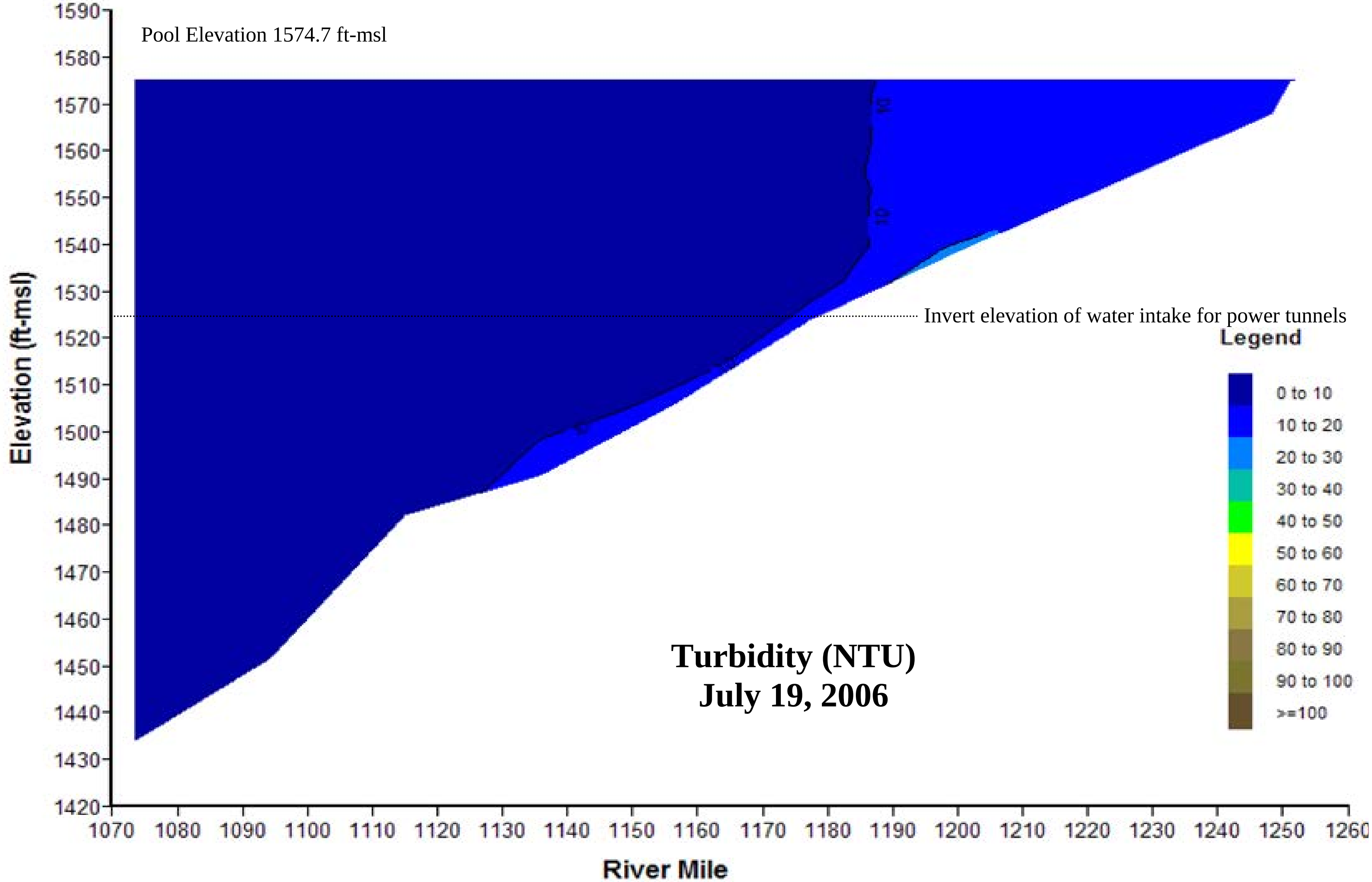

Plate 30. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 19, 2006.

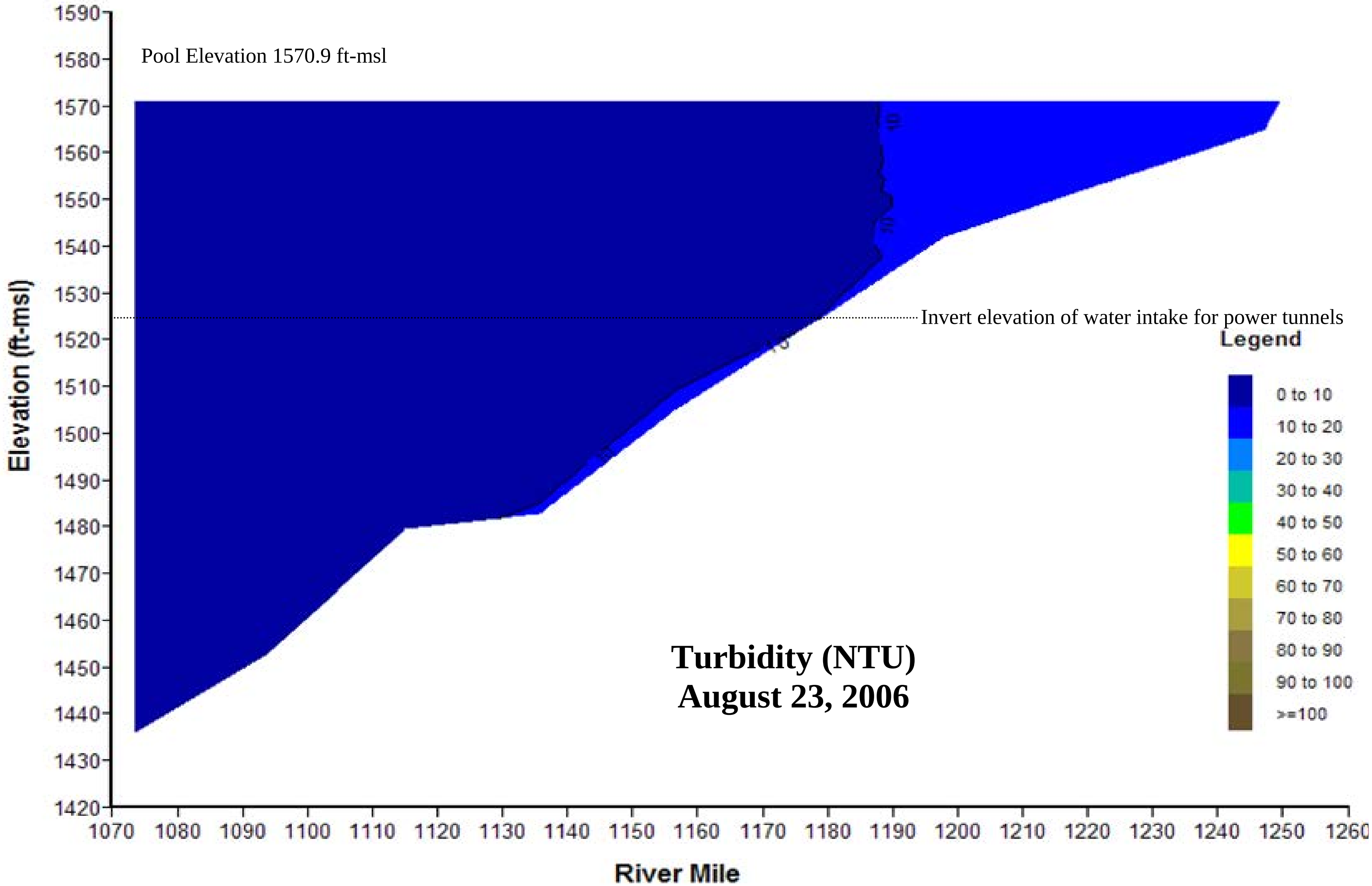

Plate 31. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 23, 2006.

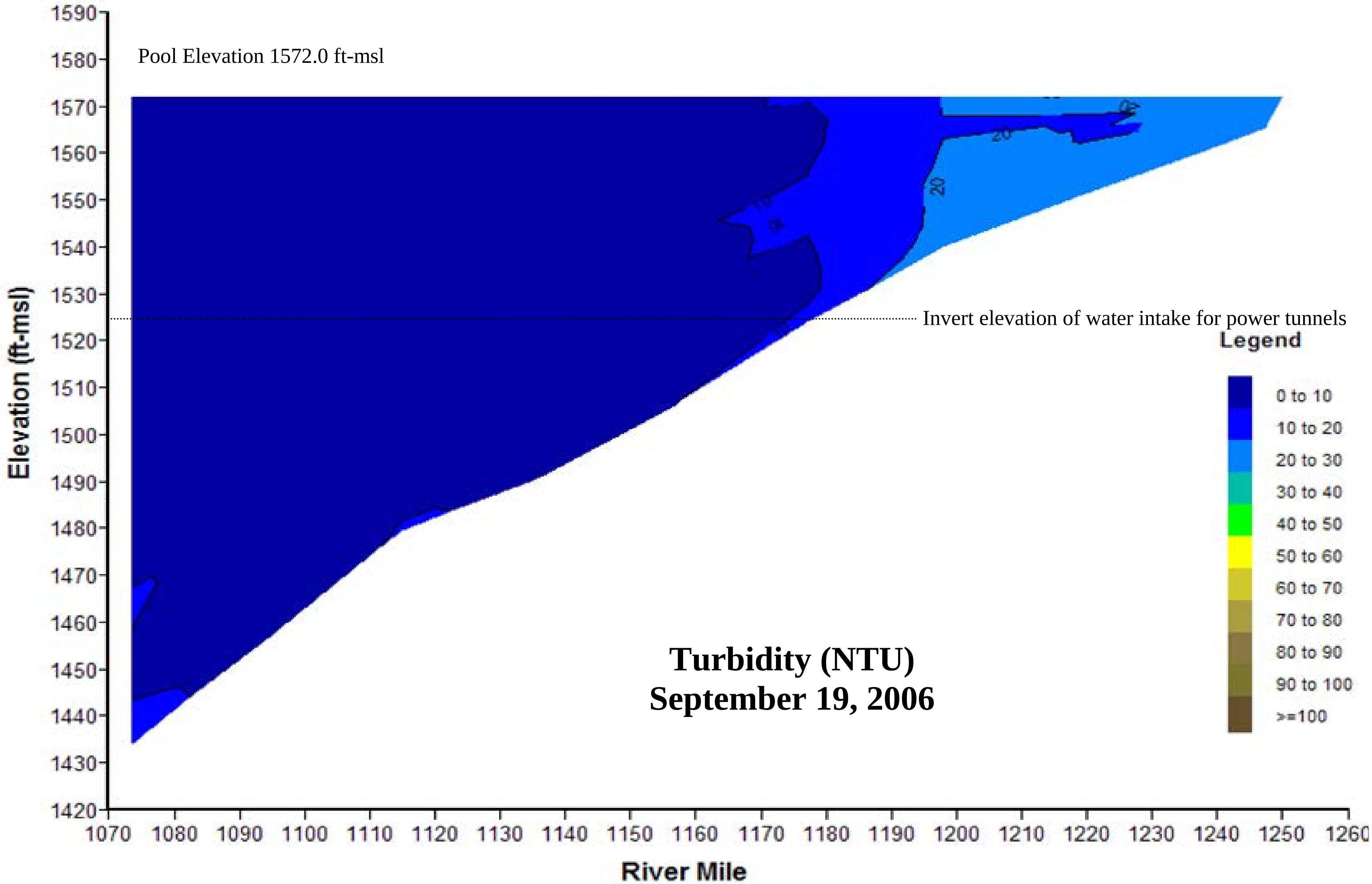

Plate 32. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 19, 2006.

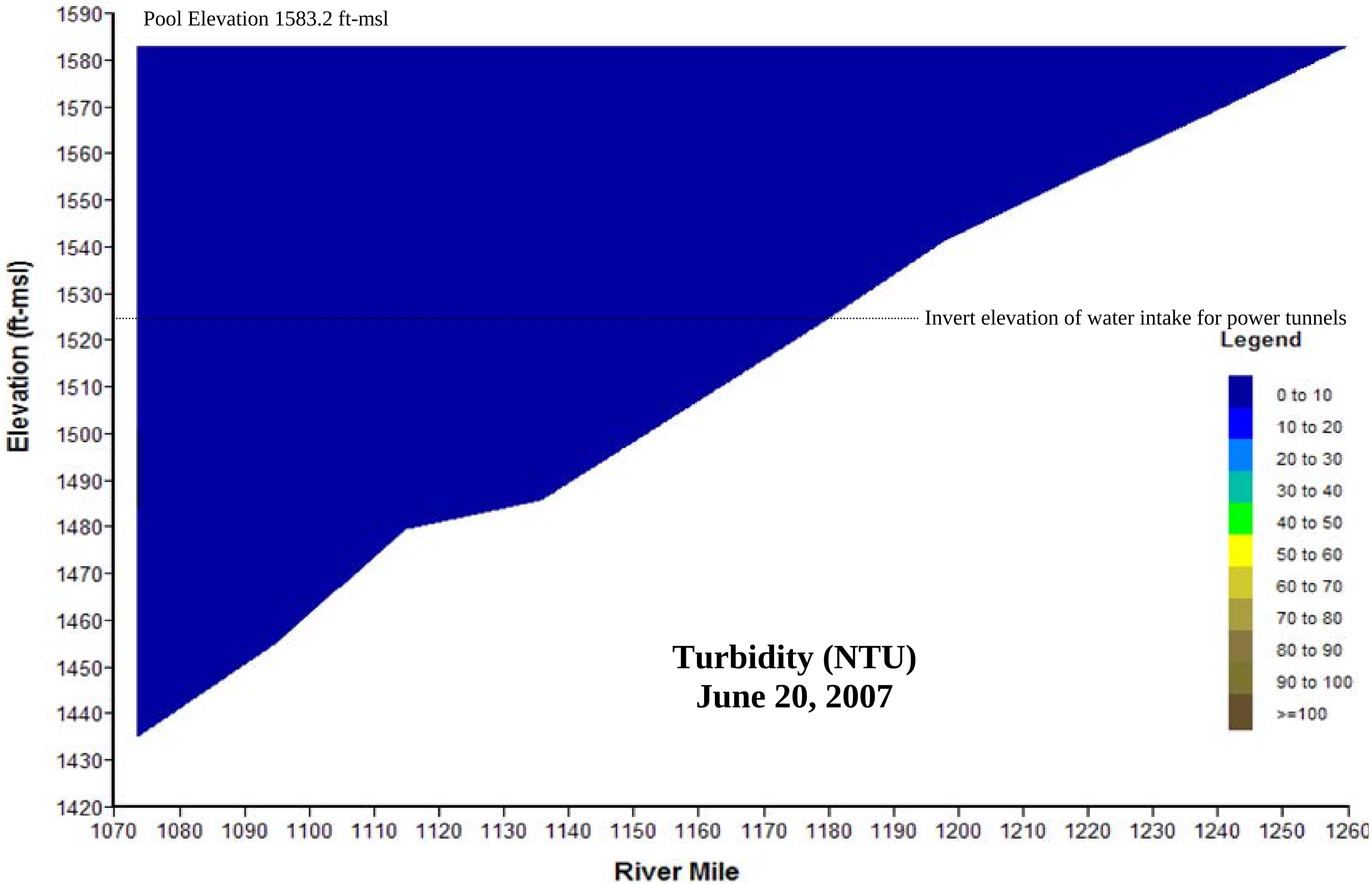

Plate 33. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on June 20, 2007.

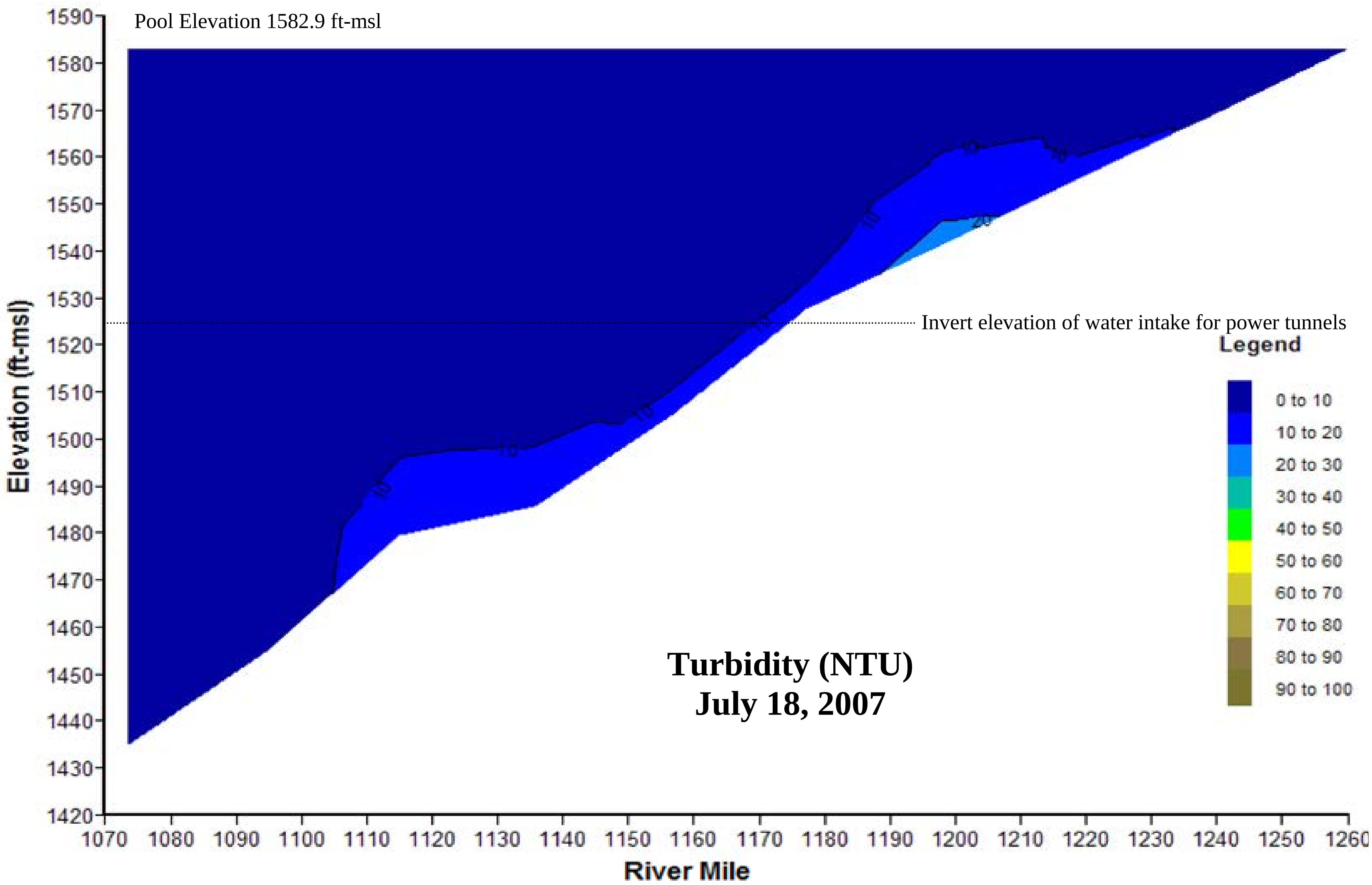

Plate 34. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on July 18, 2007.

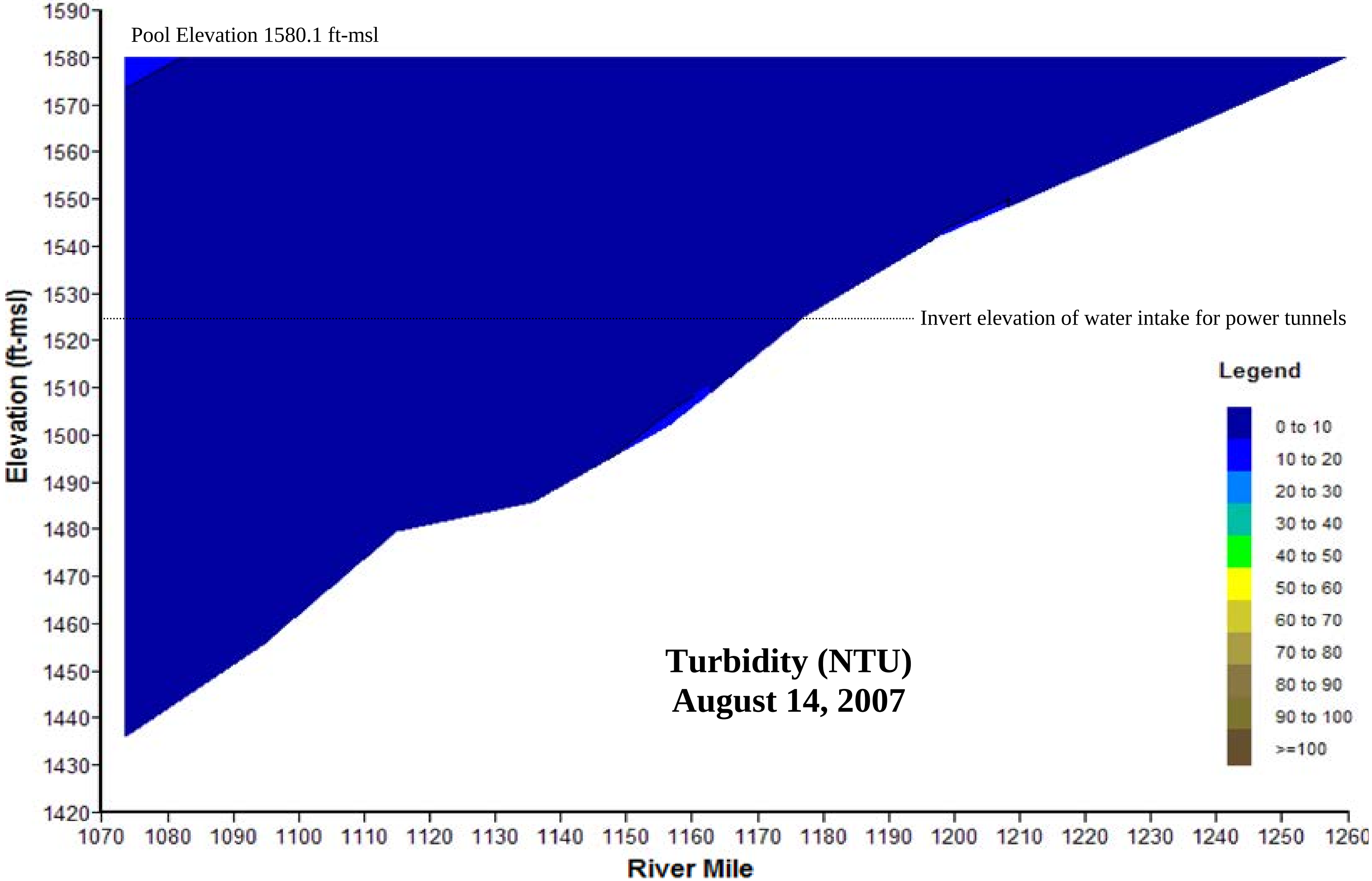

Plate 35. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on August 14, 2007.

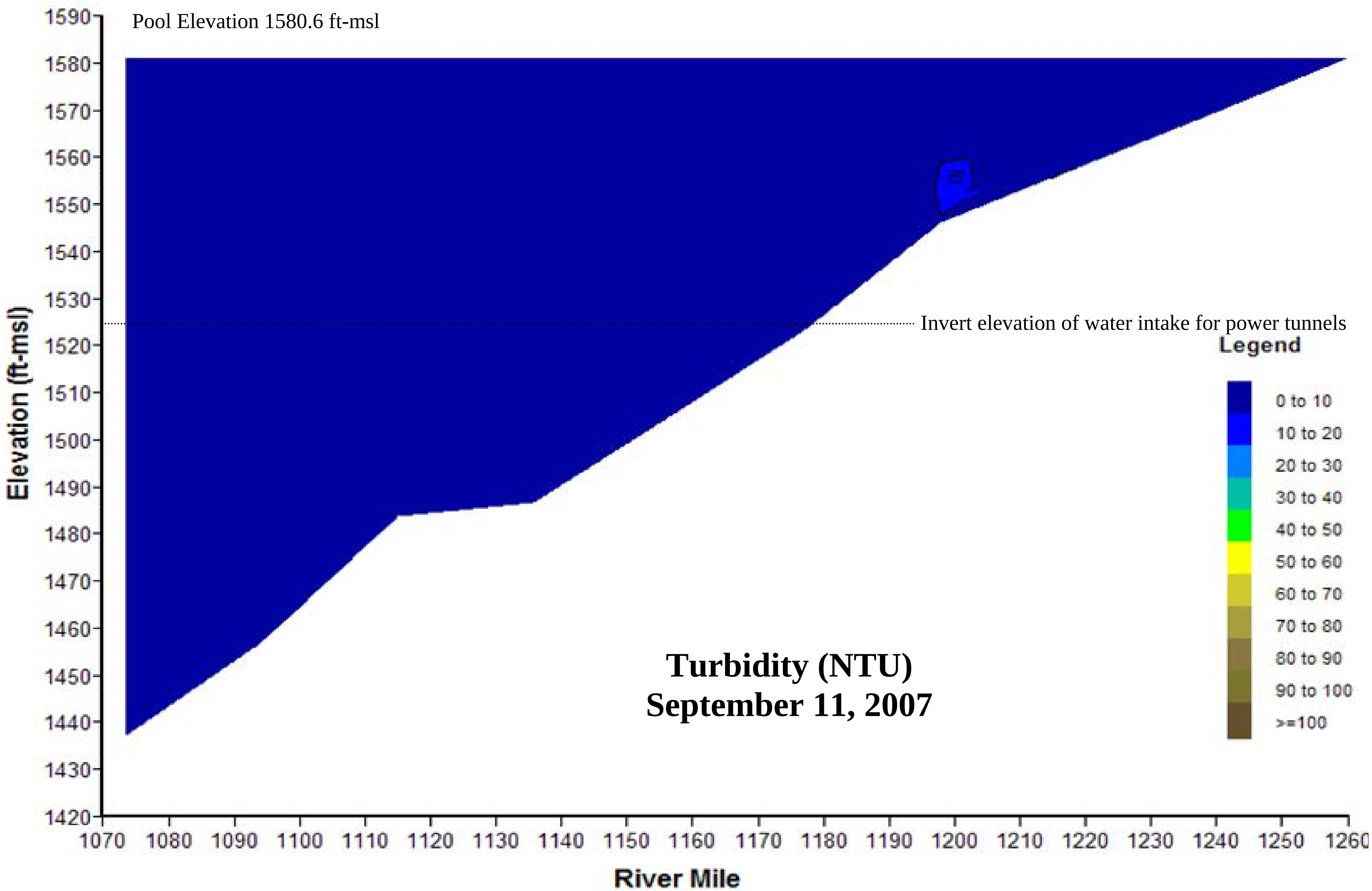

Plate 36. Longitudinal turbidity contour plot of Oahe Reservoir based on depth-profile turbidity levels monitored at sites L1, L2, L3, L4, L5, L6, and L7 on September 11, 2007.

Plate 37. Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Oahe Reservoir at site L1 during the 3-year period 2005 through 2007.

Date	Total Sample Biovolume (um^3)	Bacillariophyta		Chlorophyta		Chrysophyta		Cryptophyta		Cyanobacteria		Pyrrophyta		Euglenophyta		Shannon-Weaver Genera Diversity
		No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	
May 2005	185,149,541	3	0.96	2	0.01	1	<0.01	1	0.03	0	-----	0	-----	0	-----	0.96
Jun 2005	55,201,496	4	0.58	1	0.8	0	-----	1	0.11	3	0.02	1	0.22	0	-----	1.78
Jul 2005	45,943,019	4	0.31	2	0.04	1	0.35	1	0.04	3	0.02	1	0.25	0	-----	1.73
Aug 2005	37,779,368	5	0.84	1	0.12	0	-----	0	-----	3	0.04	0	-----	0	-----	1.58
Sep 2005	100,194,654	9	0.46	7	0.09	2	0.14	2	0.04	4	0.22	1	0.05	0	-----	2.39
May 2006	186,720,908	8	0 97	3	0.01	0	-----	1	0.01	0	-----	1	0.02	0	-----	1.31
Jun 2006	95,437,433	5	0.76	6	0.18	0	-----	1	0.05	0	-----	0	-----	1	0.01	1.52
Jul 2006	21,592,424	4	0.17	8	0.46	0	-----	1	0.29	2	0.08	0	-----	0	-----	2.25
Aug 2006	52,731,261	5	0.42	2	0.06	1	0.08	1	0.11	3	0.11	1	0.22	0	-----	2.05
Sep 2006	72,290,329	5	0.12	7	0.26	0	-----	1	0.17	2	0.26	1	0.19	0	-----	2.06
May 2007	116,487,228	7	0.69	5	0.16	2	0.04	1	0.10	0	-----	1	0.01	0	-----	2.09
Jun 2007	688,764,256	4	0.85	6	0.03	2	0.09	1	0.02	0	-----	2	0.02	0	-----	1.03
Jul 2007	112,682,481	9	0.71	7	0.04	0	-----	1	0.12	0	-----	2	0.12	0	-----	1.52
Aug 2007	45,414,995	3	0.04	7	0.08	1	0.11	1	0.35	2	0.07	1	0.35	0	-----	1.63
Sep 2007	211,489,007	5	0.40	10	0.03	1	0.11	2	0.01	5	0.03	1	0.41	0	-----	1.45
Mean*	**135,191,893**	**5.33**	**0.55**	**4.93**	**0.16**	**0.73**	**0.12**	**1.07**	**0.10**	**1.80**	**0.09**	**0 87**	**0.17**	**0.07**	**0.01**	**1.69**

* Mean percent composition represents the mean when taxa of that division are present.

Plate 38. Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Oahe Reservoir at site L3 during the 3-year period 2005 through 2007.

Date	Total Sample Biovolume (um^3)	Bacillariophyta		Chlorophyta		Chrysophyta		Cryptophyta		Cyanobacteria		Pyrrophyta		Euglenophyta		Shannon-Weaver Genera Diversity
		No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	
Jun 2005	312,053,421	4	0.84	3	0.08	1	<0.01	2	0.06	4	0.02	0	-----	0	-----	1.06
Aug 2005	140,479,427	6	0.30	2	0.08	1	0.07	1	0.29	2	0.05	2	0.22	0	-----	2.16
Sep 2005	162,991,360	5	0.35	4	0.08	1	<0.01	2	0.10	4	0.25	2	0.22	0	-----	2.02
Jun 2006	546,334,257	6	0.97	5	0.01	2	<0.01	1	0.02	3	<0.01	1	<0.01	0	-----	0.64
Jul 2006	83,678,531	6	0.14	3	0.22	0	-----	1	0.19	4	0.20	2	0.24	0	-----	2.19
Aug 2006	300,970,747	6	0.46	5	0.09	0	-----	1	<0.01	3	0.41	1	0.04	0	-----	1.88
Sep 2006	168,663,712	6	0.22	15	0.30	1	0.02	1	0.30	3	0.04	2	0.12	2	<0.01	2.53
Jun 2007	2,874,771,946	6	0.88	7	0.01	2	0.07	1	0.01	0	-----	1	0.03	0	-----	1.05
Jul 2007	61,788,273	8	0.14	6	0.13	1	0.38	1	0.13	1	0.01	1	0.22	0	-----	1.80
Aug 2007	189,011,871	7	0 31	10	0.10	0	-----	1	0.09	1	0.30	1	0.20	1	<0.01	1.99
Sep 2007	127,037,794	5	0.13	8	0.06	1	0.02	1	0.06	6	0.16	1	0.56	1	0.01	1.75
Mean*	**451,616,485**	**5.91**	**0.43**	**6.18**	**0.11**	**0.91**	**0.07**	**1.18**	**0.11**	**2.82**	**0.14**	**1 27**	**0.19**	**0.36**	**<0.01**	**1.73**

* Mean percent composition represents the mean when taxa of that division are present.

Plate 39. Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Oahe Reservoir at site L5 during the 3-year period 2005 through 2007.

Date	Total Sample Biovolume (um^3)	Bacillariophyta		Chlorophyta		Chrysophyta		Cryptophyta		Cyanobacteria		Pyrrophyta		Euglenophyta		Shannon-Weaver Genera Diversity
		No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	No. of Genera	Percent Comp.	
Jun 2005	2,103,413	0	-----	0	-----	0	-----	2	0.83	2	0.17	0	-----	0	-----	0.55
Jul 2005	121,465,212	5	0.44	2	0.02	1	0.50	2	0.04	2	<0.01	1	<0.01	0	-----	1.38
Aug 2005	375,380,230	5	0.79	8	0.14	0	-----	2	0.06	5	0.01	1	0.01	0	-----	1.10
Sep 2005	20,836,490	5	0.60	7	0.03	0	-----	1	0.16	5	0.16	1	0.06	0	-----	1.74
Jun 2006	2,880,967,056	8	0.74	13	0.25	1	<0.01	1	<0.01	1	<0.01	1	<0.01	0	-----	0.98
Jul 2006	404,261,840	3	0.87	6	0.03	1	0.02	1	0.03	2	0.03	1	0.02	0	-----	0.70
Aug 2006	116,503,830	7	0 22	10	0.28	1	<0.01	1	0.14	5	0.31	2	0.04	1	<0.01	2.38
Sep 2006	121,255,178	6	0.52	12	0.25	0	-----	1	0.06	4	0.06	1	0.05	2	0.05	2.23
Jun 2007	1,767,149,650	10	0.93	10	0.06	1	<0.01	1	0.01	2	<0.01	1	<0.01	0	-----	0.55
Jul 2007	301,855,009	8	0.53	5	0.06	1	<0.01	1	0.06	2	0.11	1	0.22	1	0.02	1.55
Aug 2007	144,618,019	6	0.12	9	0.18	1	0.19	1	0.11	4	0.08	1	0.26	2	0.06	2.21
Sep 2007	231,862,268	5	0.74	14	0.13	0	-----	2	0.04	5	0.04	1	0.02	1	0.03	2.16
Mean*	**540,688,183**	**5.67**	**0.59**	**8.00**	**0.13**	**0.58**	**0.10**	**1.33**	**0.13**	**3.25**	**0.08**	**1.00**	**0.06**	**0.58**	**0.03**	**1.46**

* Mean percent composition represents the mean when taxa of that division are present.

Plate 40. Total biovolume, number of genera present, and percent composition (based on biovolume) by taxonomic division for phytoplankton grab samples collected in Oahe Reservoir at site L7 during the 3-year period 2005 through 2007.

Date	Total Sample Biovolume (um^3)	Bacillariophyta		Chlorophyta		Chrysophyta		Cryptophyta		Cyanobacteria		Pyrrophyta		Euglenophyta		Shannon-Weaver Genera Diversity
		No. of Genera	**Percent Comp.**	**No. of Genera**	**Percent Comp.**	**No. of Genera**	**Percent Comp.**	**No. of Genera**	**Percent Comp.**	**No. of Genera**	**Percent Comp.**	**No. of Genera**	**Percent Comp.**	**No. of Genera**	**Percent Comp.**	
Jun 2005	120,198,449	6	0 96	2	0.02	0	-----	2	0.01	2	<0.01	0	-----	0	-----	1.63
Jul 2005	630,374,805	8	0.32	12	0.14	0	-----	2	0.31	7	0.20	1	0.04	0	-----	2.24
Aug 2005	166,745,682	5	0.58	2	0.11	0	-----	2	0.26	1	0.05	0	-----	0	-----	1.83
Sep 2005	22,057,409	6	0.88	3	0.03	0	-----	1	0.09	3	<0.01	0	-----	0	-----	1.52
Jun 2006	609,612,839	6	0.98	7	0.01	0	-----	1	<0.01	2	<0.01	1	<0.01	0	-----	0.97
Jul 2006	968,250,327	10	0.98	4	<0.01	1	<0.01	1	<0.01	4	<0.01	1	0.01	1	<0.01	1.43
Aug 2006	2,060,734,486	13	0 95	6	0.02	0	-----	1	0.02	3	<0.01	2	0.01	1	<0.01	1.81
Sep 2006	852,699,287	13	0 95	8	0.03	0	-----	1	0.01	2	<0.01	1	<0.01	1	<0.01	1.82
Jun 2007	1,819,909,690	10	0 91	10	0.07	1	<0.01	1	0.01	2	0.01	0	-----	0	-----	0.67
Jul 2007	800,167,337	10	0.65	8	0.02	0	-----	1	0.04	1	0.15	2	0.15	0	-----	1.49
Aug 2007	1,497,597,364	8	0.91	8	0.02	1	<0.01	0	-----	1	0.02	1	0.03	3	0.01	1.65
Sep 2007	887,246,429	9	0.94	8	0.03	0	-----	1	0.01	3	<0.01	1	0.02	2	<0.01	0.91
Mean*	**869,632,842**	**8.67**	**0.83**	**6.50**	**0.04**	**0.25**	**<0.01**	**1 17**	**0.07**	**2.58**	**0.04**	**0.83**	**0.03**	**0.67**	**<0.01**	**1.50**

* Mean percent composition represents the mean when taxa of that division are present.

Plate 41. Dominant taxa present in phytoplankton grab samples collected at the near-dam monitoring site (site L1) at Oahe Reservoir during the period 2005 through 2007.

Date	Division	Dominant Taxa*	Percent of Total Biovolume
May 2005	Bacillariophyta	*Asterionella formossa*	0.60
	Bacillariophyta	*Fragilaria construens*	0.33
June 2005	Bacillariophyta	*Stephanodiscus spp.*	0.29
	Pyrrophyta	*Peridinium spp.*	0.22
	Bacillariophyta	*Fragilaria crotonensis*	0.14
	Bacillariophyta	*Asterionella formossa*	0.14
	Cryptophyta	*Cryptomonas spp.*	0.11
July 2005	Chrysophyta	*Dinobryon sertularia*	0.35
	Pyrrophyta	*Ceratium hirundinella*	0.25
	Bacillariophyta	*Stephanodiscus hantzschii*	0.20
August 2005	Bacillariophyta	*Asterionella formossa*	0.41
	Bacillariophyta	*Synedra spp.*	0.23
	Bacillariophyta	*Navicula spp.*	0.14
	Chlorophyta	*Chlamydomonas spp.*	0.12
September 2005	Bacillariophyta	*Aulacoseira granulata*	0.22
	Cyanobacteria	*Anabaena spp.*	0.18
	Chrysophyta	*Dinobryon sertularia*	0.13
May 2006	Bacillariophyta	*Fragilaria spp.*	0.54
	Bacillariophyta	*Asterionella formossa*	0.26
June 2006	Bacillariophyta	*Fragilaria crotonensis*	0.39
	Bacillariophyta	*Asterionella formossa*	0.26
	Chlorophyta	*Cosmarium spp.*	0.17
July 2006	Cryptophyta	*Rhodomonas minuta*	0.29
	Chlorophyta	*Cosmarium spp.*	0.17
	Chlorophyta	*Golenkinia radiata*	0.11
August 2006	Bacillariophyta	*Fragilaria crotonensis*	0.27
	Pyrrophyta	*Ceratium hirundinella*	0.22
	Cryptophyta	*Rhodomonas minuta*	0.11
September 2006	Cyanobacteria	*Anabaena spp.*	0.23
	Pyrrophyta	*Ceratium hirundinella*	0.19
	Chlorophyta	*Cosmarium spp.*	0.19
	Cryptophyta	*Rhodomonas minuta*	0.17
May 2007	Bacillariophyta	*Stephanodiscus sp.*	0.26
	Bacillariophyta	*Fragilaria capucina*	0.20
	Bacillariophyta	*Cyclotella sp.*	0.13
June 2007	Bacillariophyta	*Fragilaria capucina*	0.72
	Bacillariophyta	*Asterionella formossa*	0.12
July 2007	Bacillariophyta	*Fragilaria capucina*	0.46
	Bacillariophyta	*Tabellaria flocculosa*	0.12
	Cryptophyta	*Rhodomonas sp.*	0.12
	Pyrrophyta	*Ceratium hirundinella*	0.12
August 2007	Cryptophyta	*Rhodomonas sp.*	0.35
	Pyrrophyta	*Ceratium cornutum*	0.19
	Pyrrophyta	*Ceratium hirundinella*	0.16
	Chrysophyta	*Dinobryon sp.*	0.10
September 2007	Pyrrophyta	*Ceratium hirundinella*	0.40
	Bacillariophyta	*Fragilaria capucina*	0.37
	Chrysophyta	*Dinobryon sp.*	0.11

* Dominant taxa are genera or species (depending on identification level) that comprised more than 10% of the total sample biovolume.

Plate 42. Estimate of coldwater habitats present in Oahe Reservoir on June 15, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Region 6**	**Region 7**	**Total (acre-ft)**
Depth (meters) of 18.3°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Bottom	
Elevation (ft-msl) of 18.3°C Water	1576.9	1576.9	1576.9	1576.9	1576.9	1576.9	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	1,797,296	2,244,314	2,479,543	1,604,553	805,917	862,480	0	9,794,102
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1576.9	1576.9	1576.9	1576.9	1576.9	1576.9	1576.9	
Volume (acre-ft) of Water ≤ 23.9°C	1,797,296	2,244,314	2,479,543	1,604,553	805,917	862,480	1,273,153	11,067,256
Depth of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	1,797,296	2,244,314	2,479,543	1,604,553	805,917	862,480	1,273,153	11,067,256
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	1,797,296	2,244,314	2,479,543	1,604,553	805,917	862,480	1,273,153	11,067,256
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	1,797,296	2,244,314	2,479,543	1,604,553	805,917	862,480	0	9,794,102
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	1576.9 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,797,296	2,244,314	2,479,543	1,604,553	805,917	862,480	1,273,153	11,067,256

Note: Pool elevation on June 15, 2005 = 1576.9 ft-msl. Approximate reservoir volume on June 15, 2005 = 11,067,256 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 43. Estimate of coldwater habitats present in Oahe Reservoir on July 13, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	15.0	14.1	14.5	20.2	19.5	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1528.4	1531.3	1530.0	1511.3	1513.6	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	1,045,412	1,201,271	957,047	294,939	113,031	0	0	3,611,700
Depth (meters) of 23.9°C Water	Surface	5.0	5.2	1.8	4.0	8.5	10.5	
Elevation (msl) of 23.9°C Water	1577.6	1561.2	1560.5	1571.7	1564.5	1549.7	1543.1	
Volume (acre-ft) of Water ≤ 23.9°C	1,809,641	1,851,176	1,859,981	1,468,974	616,604	317,277	178,821	8,102,474
Depth of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	19.0	15.2	11.5	
Elevation of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	1515.3	1527.7	1539.9	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	0	0	122,131	124,323	138,478	384,932
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	16.2	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	1524.4	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	102,015	0	102,015
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1528.4 to Bottom	1531.3 to Bottom	1530.0 to Bottom	1511.3 to Bottom	0	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	1,045,412	1,201,271	957,047	294,939	0	0	0	3,498,669
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1577.6 to Bottom	1561.2 to Bottom	1560.5 to Bottom	1571.7 to Bottom	1564.5 to Bottom	1549.7 to 1524.4	1543.1 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,809,641	1,851,176	1,859,981	1,468,974	616,604	215,262	178,821	8,000,459

Note: Pool elevation on July 13, 2005 = 1577.6 ft-msl. Approximate reservoir volume on July 13, 2005 = 11,214,027 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 44. Estimate of coldwater habitats present in Oahe Reservoir on August 17, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	16.2	18.8	20.2	17.5	20.3	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1522.3	1513.8	1509.2	1518.1	1508.9	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	962,327	867,947	504,457	378,879	88,533	0	0	2,802,143
Depth (meters) of 23.9°C Water	Surface	Surface	3.2	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1575.5	1575.5	1565.0	1575.5	1575.5	1575.5	1575.5	
Volume (acre-ft) of Water ≤ 23.9°C	1,772,608	2,207,165	2,015,729	1,567,227	782,980	812,215	1,193,782	10,351,706
Depth of 6 mg/l DO Water	Bottom	Bottom	19.0	17.3	14.2	14.0	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	1513.2	1518.7	1528.9	1529.6	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO			584,415	387,012	205,279	137,407	0	1,314,113
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	18.5	16.1	16.3	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1514.8	1522.7	1522.0	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO				334,592	163,905	87,151	0	585,648
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1522.3 to Bottom	1513.8 to Bottom	0	0	0	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	962,327	867,947	0	0	0	0	0	1,830,274
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1575.5 to Bottom	1575.5 to Bottom	1565.0 to Bottom	1575.5 to 1514.8	1575.5 to 1522.7	1575.5 to 1522.0	1575.5 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,772,608	2,207,165	2,015,729	1,232,635	619,075	725,064	1,193,782	9,766,058

Note: Pool elevation on August 17, 2005 = 1575.5 ft-msl. Approximate reservoir volume on August 17, 2005 = 10,773,714 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 45. Estimate of coldwater habitats present in Oahe Reservoir on September 14, 2005 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	24.5	20.7	19.4	23.8	Bottom	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1493.1	1505.6	1509.8	1495.4	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	587,829	722,676	515,749	157,107	0	0	0	1,983,361
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1573.5	1573.5	1573.5	1573.5	1573.5	1573.5	1573.5	
Volume (acre-ft) of Water ≤ 23.9°C	1,737,982	2,155,260	2,341,402	1,515,295	751,330	781,443	1,088,731	10,371,443
Depth of 6 mg/l DO Water	Bottom	Bottom	20.7	23.6	Bottom	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	1505.6	1496.1	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	436,705	162,372	0	0	0	599,077
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	24.8	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1492.1	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	133,596	0	0	0	133,596
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1493.1 to Bottom	1505.6 to Bottom	1509.8 to 1505.6	0	0	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	587,829	722,676	79,044	0	0	0	0	1,389,549
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1573.5 to Bottom	1573.5 to Bottom	1573.5 to Bottom	1573.5 to 1492.1	1573.5 to Bottom	1573.5 to Bottom	1573.5 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,737,982	2,155,260	2,341,402	1,381,699	751,330	781,443	1,088,731	10,237,847

Note: Pool elevation on September 14, 2005 = 1573.5 ft-msl. Approximate reservoir volume on September 14, 2005 = 10,371,443 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 46. Estimate of coldwater habitats present in Oahe Reservoir on June 14, 2006 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	6.2	Surface	5.0	7.7	Bottom	
Elevation (ft-msl) of 18.3°C Water	1576.7	1576.7	1556.4	1576.7	1560.3	1551.4	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	1,793,769	2,239,007	1,722,515	1,599,220	558,546	313,627	0	8,226,684
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1576.7	1576.7	1576.7	1576.7	1576.7	1576.7	1576.7	
Volume (acre-ft) of Water ≤ 23.9°C	1,793,769	2,239,007	2,471,285	1,599,220	802,640	857,585	1,261,815	11,025,321
Depth of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	0	0	0	0	0	0
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1576.7 to Bottom	1576.7 to Bottom	1556.4 to Bottom	1576.7 to Bottom	1560.3 to Bottom	1551.4 to Bottom	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	1,793,769	2,239,007	1,722,515	1,599,220	558,546	313,627	0	8,226,684
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1576.7 to Bottom	1576.7 to Bottom	1576.7 to Bottom	1576.7 to Bottom	1576.7 to Bottom	1576.7 to Bottom	1576.7 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,793,769	2,239,007	2,471,285	1,599,220	802,640	857,585	1,261,815	11,025,321

Note: Pool elevation on June 14, 2006 = 1576.7 ft-msl. Approximate reservoir volume on June 14, 2006 = 11,025,321 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 47. Estimate of coldwater habitats present in Oahe Reservoir on July 19, 2006 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	11.0	14.7	19.1	14.0	15.1	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1538.6	1526.5	1512.0	1528.8	1525.2	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	1,190,707	1,106,818	560,076	551,324	178,548	0	0	3,587,473
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Bottom	
Elevation (msl) of 23.9°C Water	1574.7	1574.7	1574.7	1574.7	1574.7	1574.7	Bottom	
Volume (acre-ft) of Water ≤ 23.9°C	1,758,628	2,186,170	2,389,154	1,546,176	770,097	809,071	0	9,459,296
Depth of 6 mg/l DO Water	Bottom	Bottom	Bottom	23.0	14.0	12.4	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	Bottom	1499.2	1528.8	1534.0	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	0	185,687	204,557	170,499	0	560,743
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	20.0	15.0	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	1509.1	1525.5	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	0	89,517	109,174	0	198,691
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1538.6 to Bottom	1526.5 to Bottom	1512.0 to Bottom	1528.8 to 1499.2	0	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	1,190,707	1,106,818	560,076	365,637	0	0	0	3,223,238
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1574.7 to Bottom	1574.7 to Bottom	1574.7 to Bottom	1574.7 to Bottom	1574.7 to 1509.1	1574.7 to 1525.5	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,758,628	2,186,170	2,389,154	1,546,176	680,580	699897	0	9,260,605

Note: Pool elevation on July 19, 2006 = 1574.7 ft-msl. Approximate reservoir volume on July 19, 2006 = 10,609,390 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 48. Estimate of coldwater habitats present in Oahe Reservoir on August 23, 2006 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	17.5	18.9	22.4	18.2	19.9	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1513.5	1508.9	1497.4	1511.2	1521.7	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	844,827	780,112	323,367	293,806	158,167	0	0	2,400,279
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1570.9	1570.9	1570.9	1570.9	1570.9	1570.9	1570.9	
Volume (acre-ft) of Water ≤ 23.9°C	1,693,247	2,088,287	2,237,942	1,448,386	710,668	721,583	955,777	9,855,890
Depth of 6 mg/l DO Water	Bottom	Bottom	22.8	17.0	15.7	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	1496.1	1515.1	1519.4	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	308,235	338,214	145,056	0	0	791,505
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	20.5	16.8	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1503.6	1515.8	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	220,548	124,926	0	0	345,474
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1513.5 to Bottom	1508.9 to Bottom	1497.4 to 1496.1	0	0	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	844,827	780,112	15,132	0	0	0	0	1,640,071
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1570.9 to Bottom	1570.9 to Bottom	1570.9 to Bottom	1570.9 to 1503.6	1570.9 to 1515.8	1570.9 to Bottom	1570.9 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,693,247	2,088,287	2,237,942	1,227,838	585,742	721,583	955,777	9,510,416

Note: Pool elevation on August 23, 2006 = 1570.9 ft-msl. Approximate reservoir volume on August 23, 2006 = 9,855,889 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 49. Estimate of coldwater habitats present in Oahe Reservoir on September 19, 2006 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	2.0	1.0	Surface	Surface	Surface	
Elevation (ft-msl) of 18.3°C Water	1572.0	1572.0	1565.4	1568.7	1572.0	1572.0	1572.0	
Volume (acre-ft) of Water ≤ 18.3°C	1,712,173	2,116,621	2,029,573	1,393,408	727,871	746,909	1,012,026	9,738,581
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1572.0	1572.0	1572.0	1572.0	1572.0	1572.0	1572.0	
Volume (acre-ft) of Water ≤ 23.9°C	1,712,173	2,116,621	2,281,713	1,476,694	727,871	746,909	1,012,026	10,074,007
Depth of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	0	0	0	0	0	0
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1572.0 to Bottom	1572.0 to Bottom	1565.4 To Bottom	1568.7 to Bottom	1572.0 to Bottom	1572.0 to Bottom	1572.0 to Bottom	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	1,712,173	2,116,621	2,029,573	1,393,408	727,871	746,909	1,012,026	9,738,581
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1572.0 to Bottom	1572.0 to Bottom	1572.0 to Bottom	1572.0 to Bottom	1572.0 to Bottom	1572.0 to Bottom	1572.0 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,712,173	2,116,621	2,281,713	1,476,694	727,871	746,909	1,012,026	10,074,007

Note: Pool elevation on September 19, 2006 = 1572.0 ft-msl. Approximate reservoir volume on September 19, 2006 = 10,074,007 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 50. Estimate of coldwater habitats present in Oahe Reservoir on June 20, 2007 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	Surface	Surface	7.0	5.5	14.0	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1583.2	1583.2	1560.2	1565.2	1537.3	1583.2	1583.2	
Volume (acre-ft) of Water ≤ 18.3°C	1,909,804	2,414,032	1,849,598	1,307,746	280,016	1,021,304	1,650,221	10,432,721
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1583.2	1583.2	1583.2	1583.2	1583.2	1583.2	1583.2	
Volume (acre-ft) of Water ≤ 23.9°C	1,909,804	2,414,032	2,744,679	1,775,467	911,441	1,021,304	1,650,221	12,426,948
Depth of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	0	0	0	0	0	0
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	0	0	0
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1583.2 to Bottom	1583.2 to Bottom	1560.2 to Bottom	1565.2 to Bottom	1537.3 to Bottom	1583.2 to Bottom	1583.2 to Bottom	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	1,909,804	2,414,032	1,849,598	1,307,746	280,016	1,021,304	1,650,221	10,432,721
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1583.2 to Bottom	1583.2 to Bottom	1583.2 to Bottom	1583.2 to Bottom	1583.2 to Bottom	1583.2 to Bottom	1583.2 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,909,804	2,414,032	2,744,679	1,775,467	911,441	1,021,304	1,650,221	12,426,948

Note: Pool elevation on June 20, 2007 = 1583.2 ft-msl. Approximate reservoir volume on June 20, 2007 = 12,426,948 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 51. Estimate of coldwater habitats present in Oahe Reservoir on July 18, 2007 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	18.4	17.7	19.7	18.4	16.5	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1522.5	1524.8	1518.3	1522.5	1528.8	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	965,023	6,762,738	691,401	445,353	204,557	0	0	9,069,072
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	4.5	7.0	9.0	
Elevation (msl) of 23.9°C Water	1582.9	1582.9	1582.9	1582.9	1568.1	1559.9	1553.4	
Volume (acre-ft) of Water ≤ 23.9°C	1,904,381	2,405,833	2,731,823	1,767,192	668,823	494,001	362,713	10,334,766
Depth of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	22.0	12.7	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	1510.7	1541.2	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	0	0	97,655	229,801	0	327,456
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	16.0	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	Bottom	Bottom	1530.4	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	0	0	143,195	0	143,195
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1522.5 to Bottom	1524.8 to Bottom	1518.3 to Bottom	1522.5 to Bottom	1528.8 to Bottom	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	965,023	6,762,738	691,401	445,353	106,902	0	0	8,971,417
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1582.9 to Bottom	1582.9 to Bottom	1582.9 to Bottom	1582.9 to Bottom	1582.9 to Bottom	1582.9 to 1530.4	1582.9 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,904,381	2,405,833	2,731,823	1,767,192	668,823	350,806	362,713	10,191,571

Note: Pool elevation on July 18, 2007 = 1582.9 ft-msl. Approximate reservoir volume on July 18, 2007 = 12,360,412 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 52. Estimate of coldwater habitats present in Oahe Reservoir on August 14, 2007 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Region 6**	**Region 7**	**Total (acre-ft)**
Depth (meters) of 18.3°C Water	17.4	19.9	19.9	18.8	22.7	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1523.0	1514.8	1514.8	1518.4	1505.6	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	971,761	886,023	616,866	382,945	72,301	0	0	2,929,896
Depth (meters) of 23.9°C Water	8.0	11.0	19.3	10.8	13.2	Bottom	Bottom	
Elevation (msl) of 23.9°C Water	1553.9	1544.0	1516.8	1544.7	1536.8	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 23.9°C	1,419,609	1,464,715	659,365	854,040	274,947	0	0	4,672,676
Depth of 6 mg/l DO Water	Bottom	Bottom	18.8	18.3	16.0	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	1518.4	1520.1	1527.6	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	693,537	406,262	195,887	0	0	1,295,686
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	20.0	18.3	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1514.5	1520.1	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	331,193	148,985	0	0	480,178
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1523.0 to Bottom	1514.8 to Bottom	0	0	0	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	971,761	886,023	0	0	0	0	0	1,857,784
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1553.9 to Bottom	1553.9 to Bottom	1553.9 to Bottom	1553.9 to 1514.4	1553.9 to 1520.1	0	0	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,419,609	1,464,715	659,365	522,847	125,962	0	0	4,192,498

Note: Pool elevation on August 14, 2007 = 1580.1 ft-msl. Approximate reservoir volume on August 14, 2007 = 11,739,420 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

Plate 53. Estimate of coldwater habitats present in Oahe Reservoir on September 11, 2007 based on measured water temperature and dissolved oxygen depth-profiles.

	Region 1	Region 2	Region 3	Region 4	Region 5	Region 6	Region 7	Total (acre-ft)
Depth (meters) of 18.3°C Water	23.7	23.8	19.6	22.3	23.8	Bottom	Bottom	
Elevation (ft-msl) of 18.3°C Water	1502.8	1502.5	1516.3	1507.4	1502.5	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 18.3°C	707,333	669,307	648,686	255,019	57,934	0	0	2,338,279
Depth (meters) of 23.9°C Water	Surface	Surface	Surface	Surface	Surface	Surface	Surface	
Elevation (msl) of 23.9°C Water	1580.6	1580.6	1580.6	1580.6	1580.6	1580.6	1580.6	
Volume (acre-ft) of Water ≤ 23.9°C	1,862,809	2,342,971	2,633,256	1,703,752	866,967	953,905	1,486,652	11,850,312
Depth of 6 mg/l DO Water	Bottom	Bottom	23.3	22.6	22.4	Bottom	Bottom	
Elevation of 6 mg/l DO Water	Bottom	Bottom	1504.2	1506.4	1507.1	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 6mg/l DO	0	0	413,928	245,330	79,679	0	0	738,937
Depth of 5 mg/l DO Water	Bottom	Bottom	Bottom	22.9	22.7	Bottom	Bottom	
Elevation of 5 mg/l DO Water	Bottom	Bottom	Bottom	1505.5	1506.1	Bottom	Bottom	
Volume (acre-ft) of Water ≤ 5mg/l DO	0	0	0	236,610	74,760	0	0	311,370
Thickness of Coldwater Habitat Layer (i.e., ≤ 18.3°C, and ≥ 6 mg/l DO)	1502.8 to Bottom	1502.5 to Bottom	1516.3 to 1504.2	1507.4 to 1506.4	0	0	0	
Volume (acre-ft) of Coldwater Habitat (i.e., ≤ 18.4°C, and ≥ 6 mg/l DO)*	707,333	669,307	234,758	18,409	0	0	0	1,629,807
Thickness of Marginal Coldwater Habitat Layer (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)	1580.6 to Bottom	1580.6 to Bottom	1580.6 to Bottom	1580.6 to 1505.5	1580.6 to 1506.1	1580.6 to Bottom	1580.6 to Bottom	
Volume (acre-ft) of Marginal Coldwater Habitat (i.e., ≤ 23.9°C, and ≥ 5 mg/l DO)**	1,862,809	2,342,971	2,633,256	1,467,142	792,207	953,905	1,486,652	11,538,942

Note: Pool elevation on September 11, 2007 = 1580.6 ft-msl. Approximate reservoir volume on September 11, 2007 = 11,850,312 acre-feet.

* Volume of water supportive of the coldwater permanent fish life propagation use as defined by South Dakota's surface water quality standards.

** Volume of water supportive of the coldwater marginal fish life propagation use as defined by South Dakota's surface water quality standards.

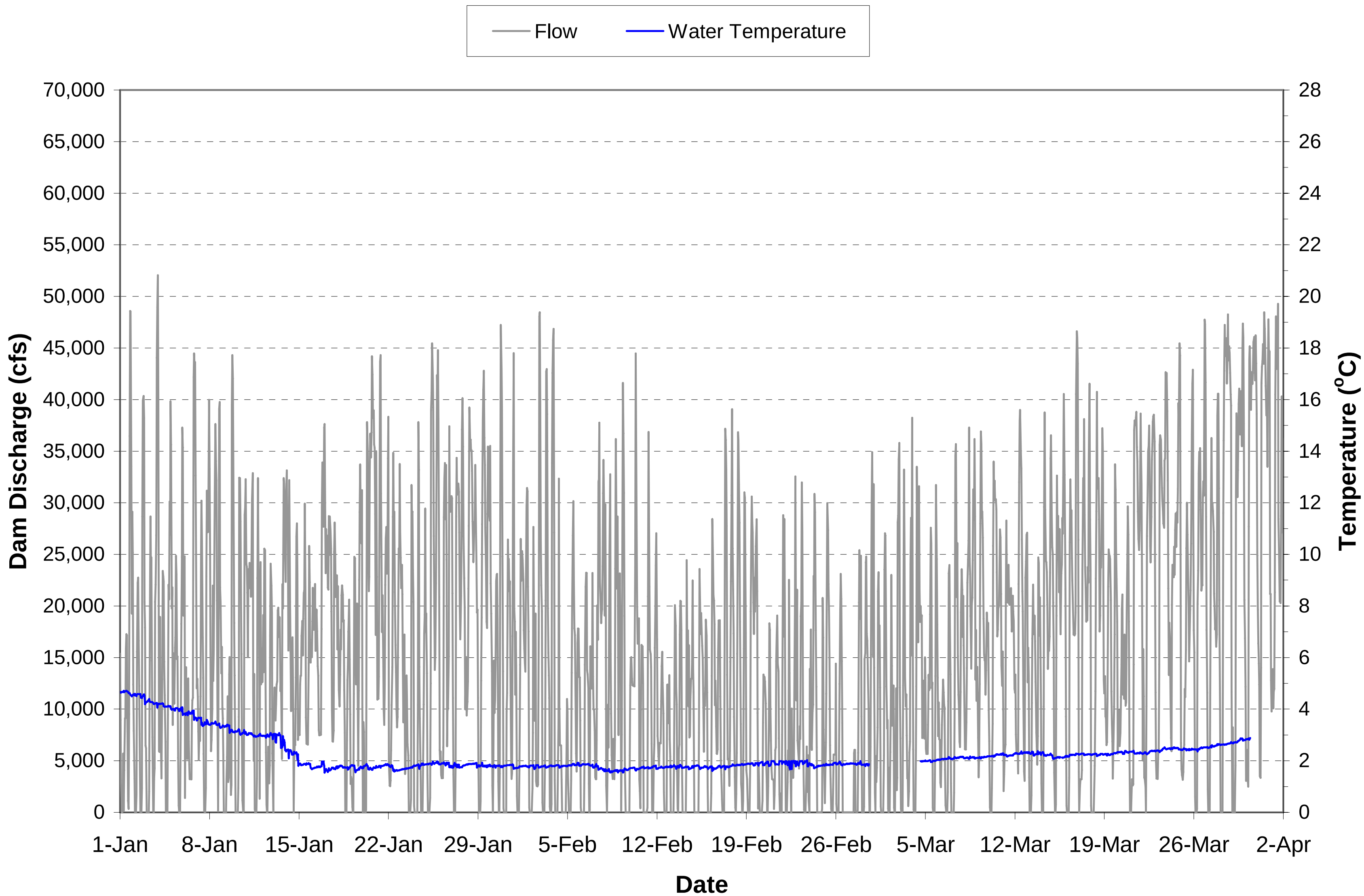

Plate 54. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period January through March 2005**.** (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

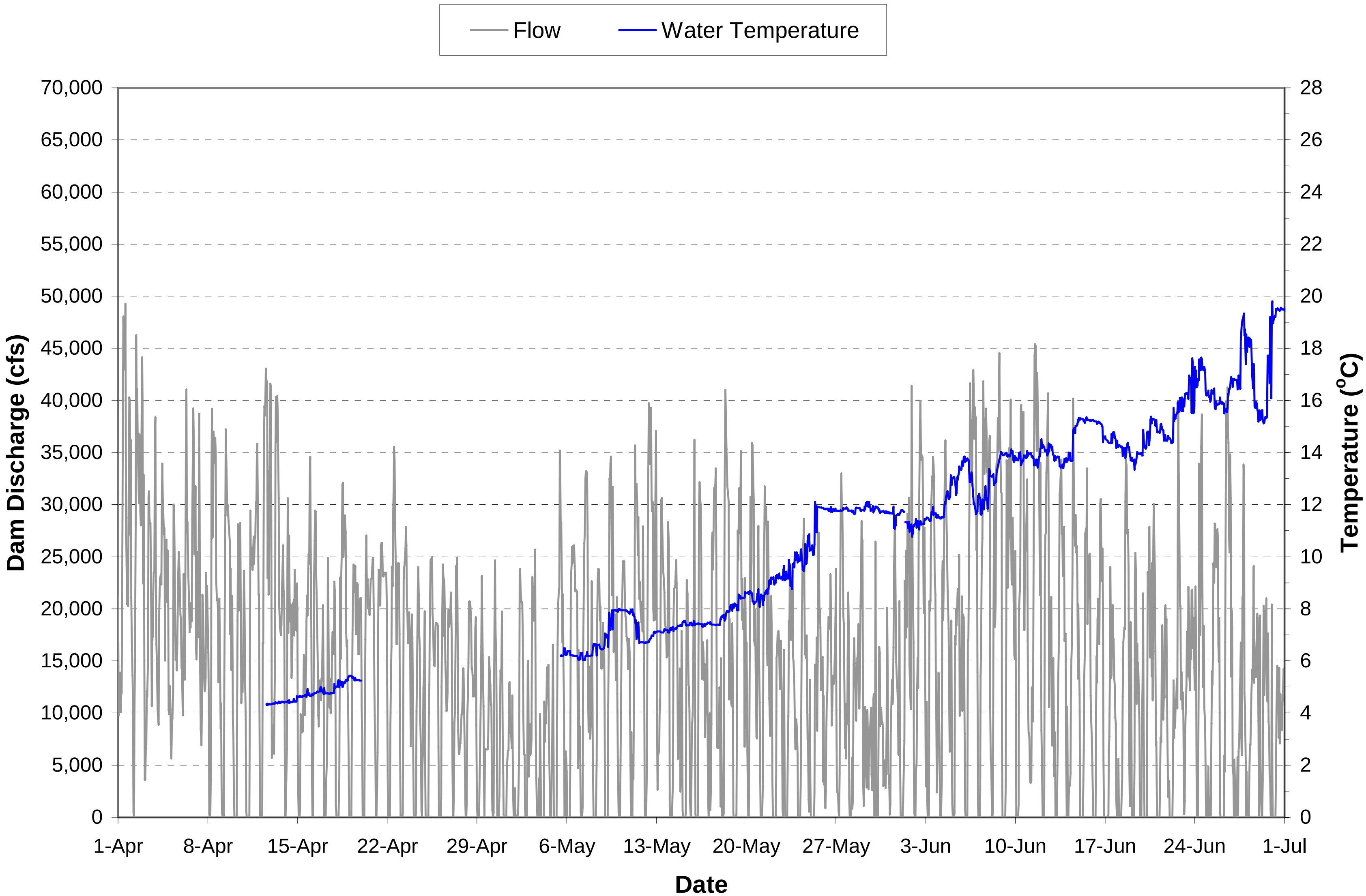

Plate 55. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period April through June 2005. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

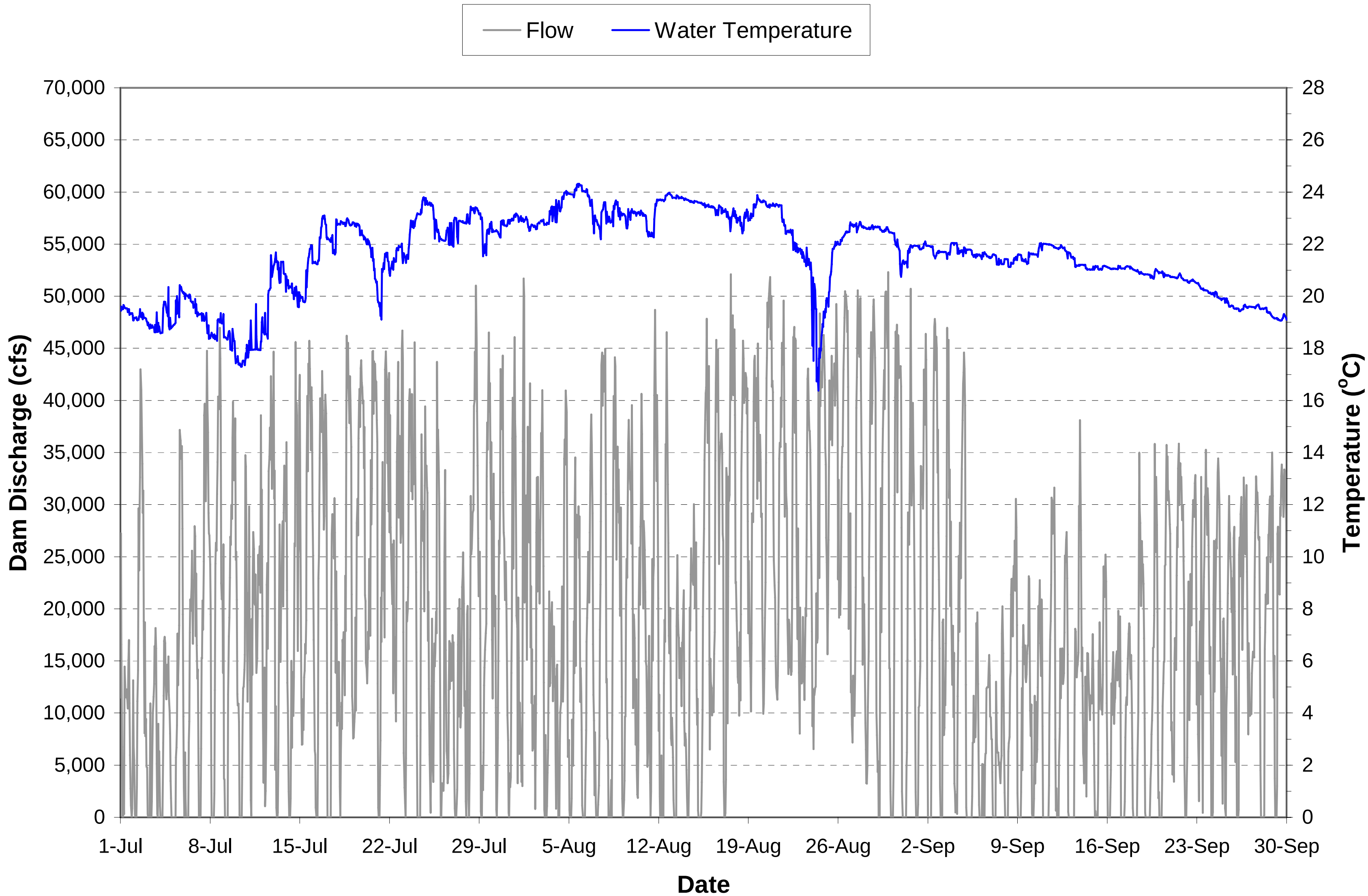

Plate 56. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period July through September 2005.

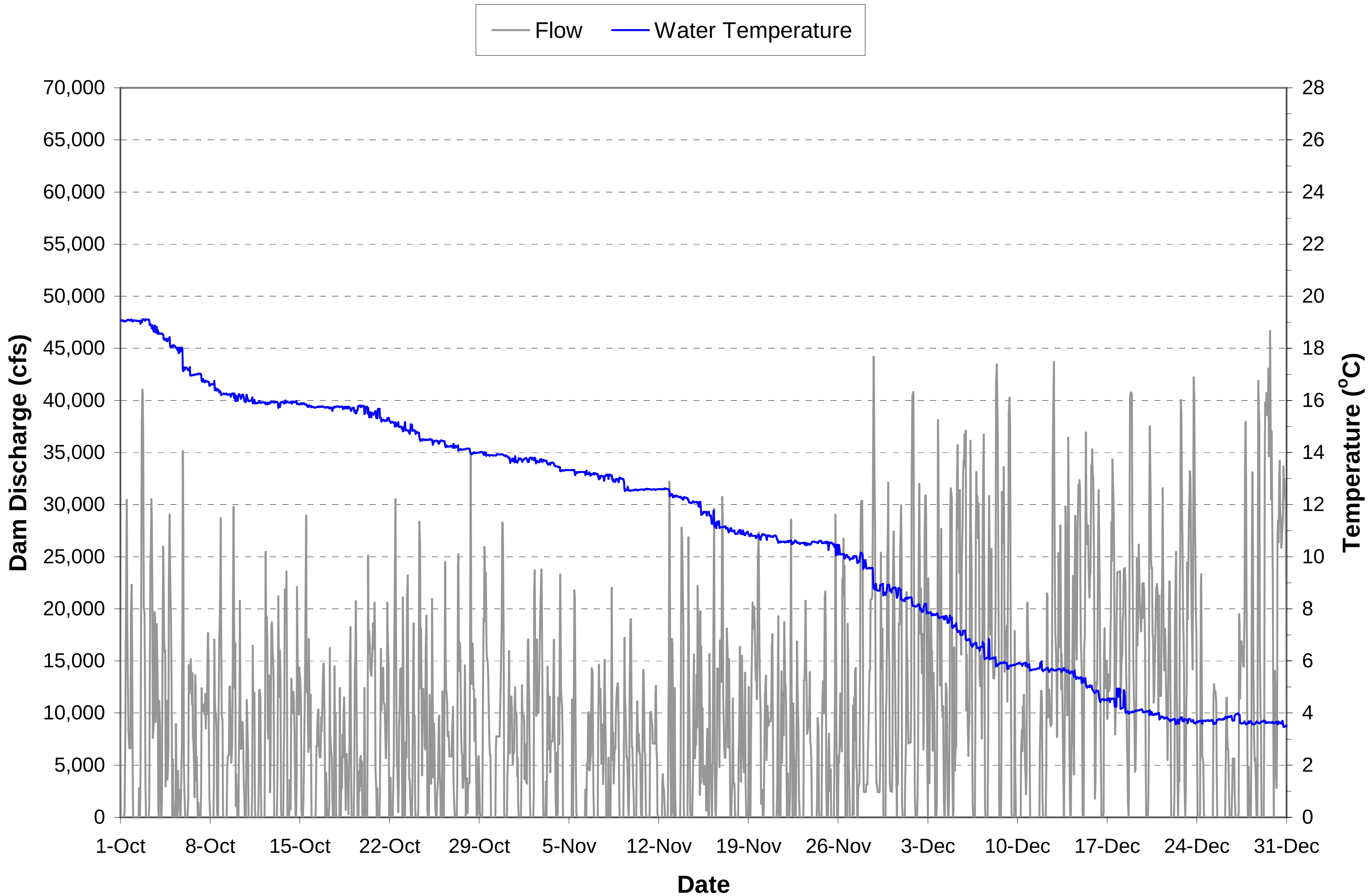

Plate 57. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period October through December 2005.

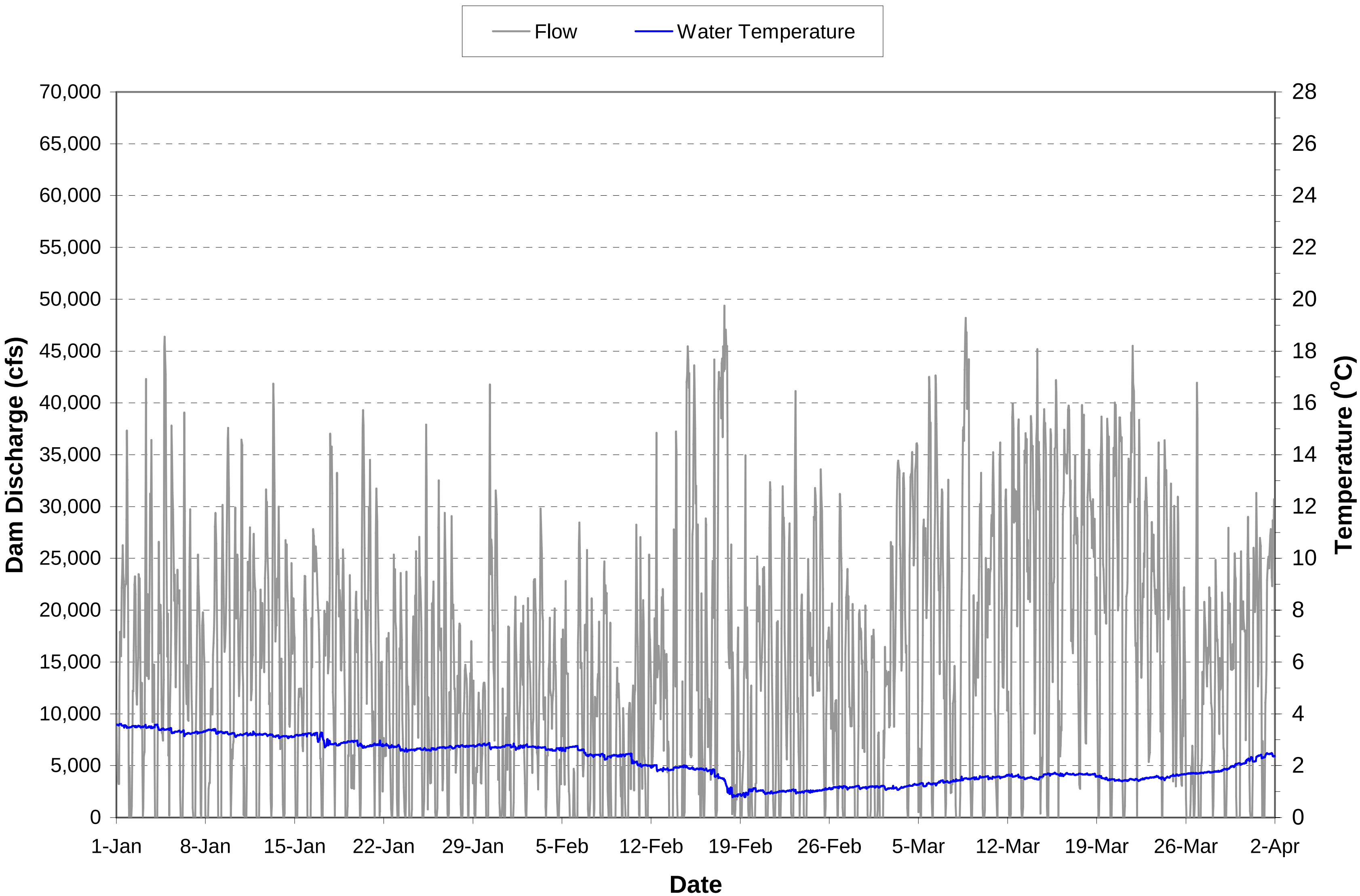

Plate 58. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period January through March 2006.

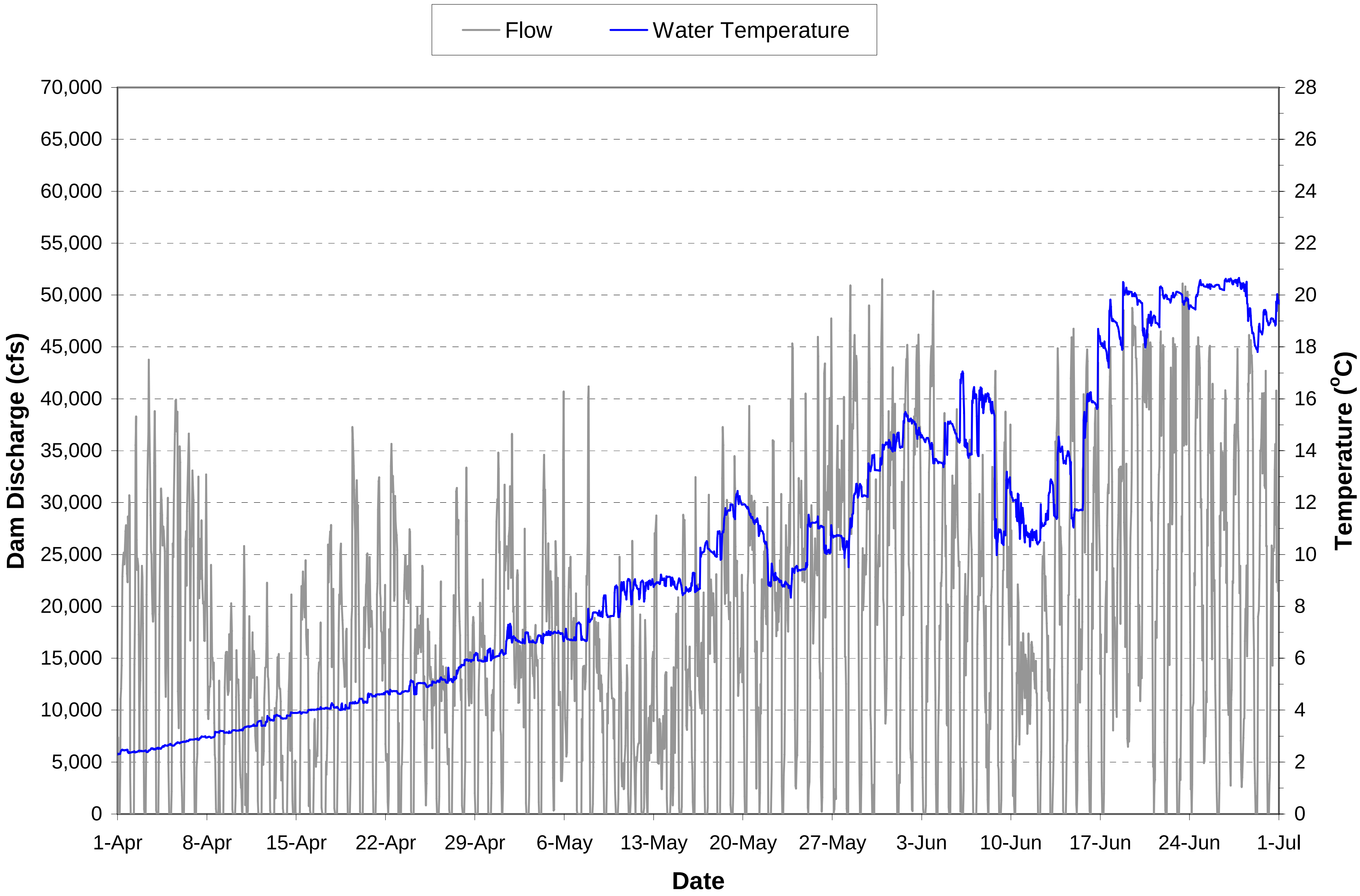

Plate 59. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period April through June 2006.

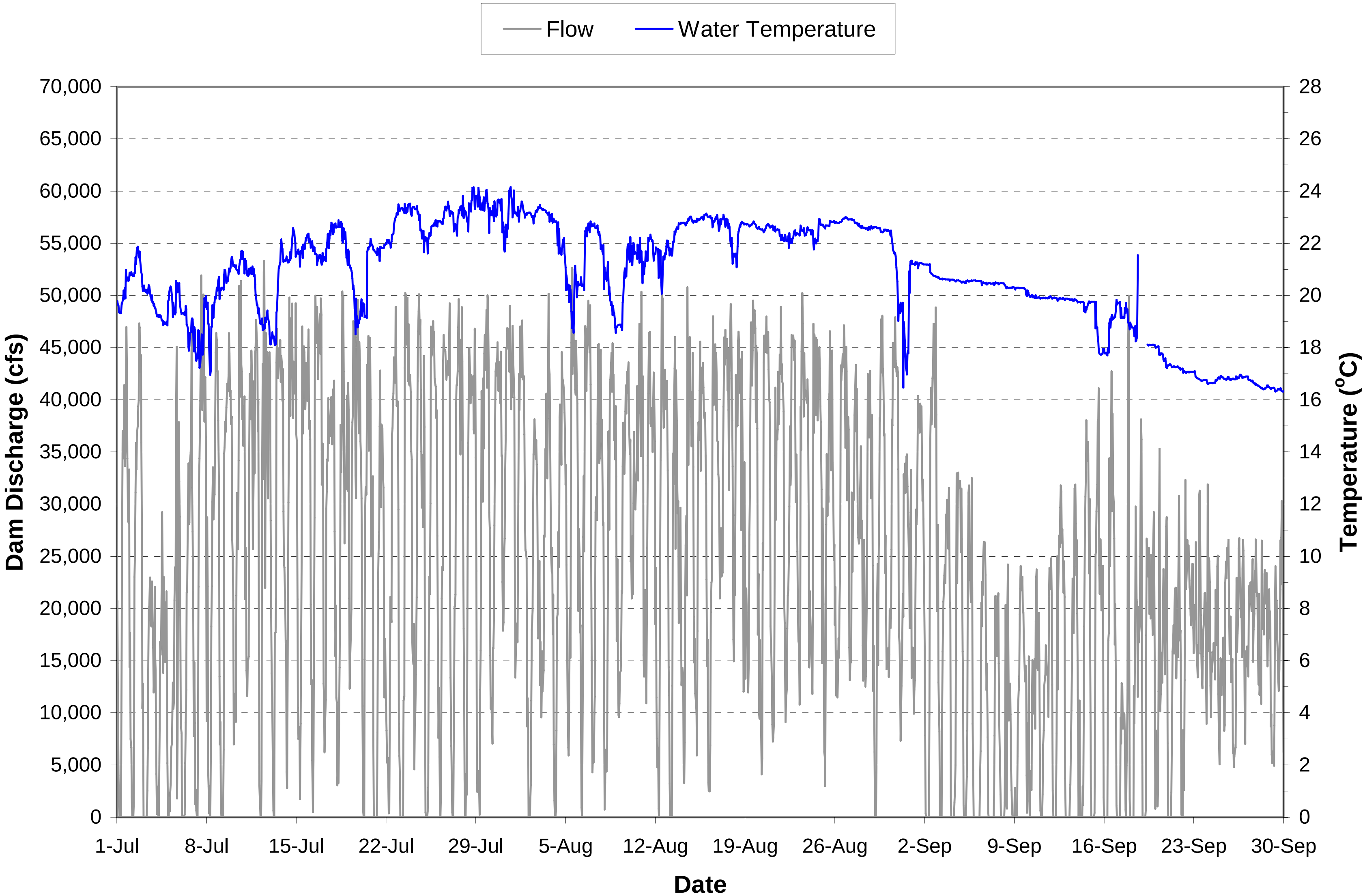

Plate 60. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period July through September 2006.

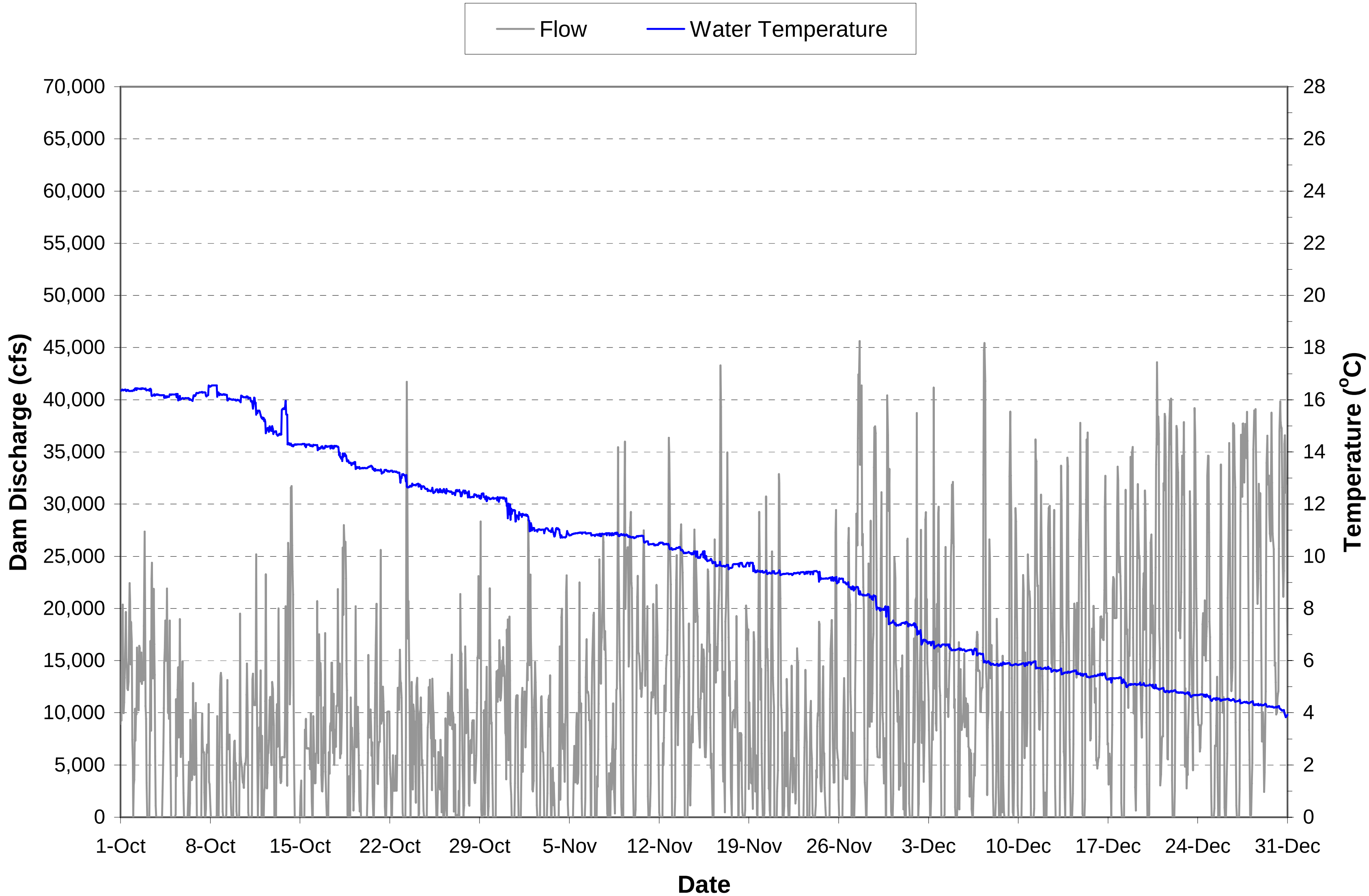

Plate 61. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period October through December 2006.

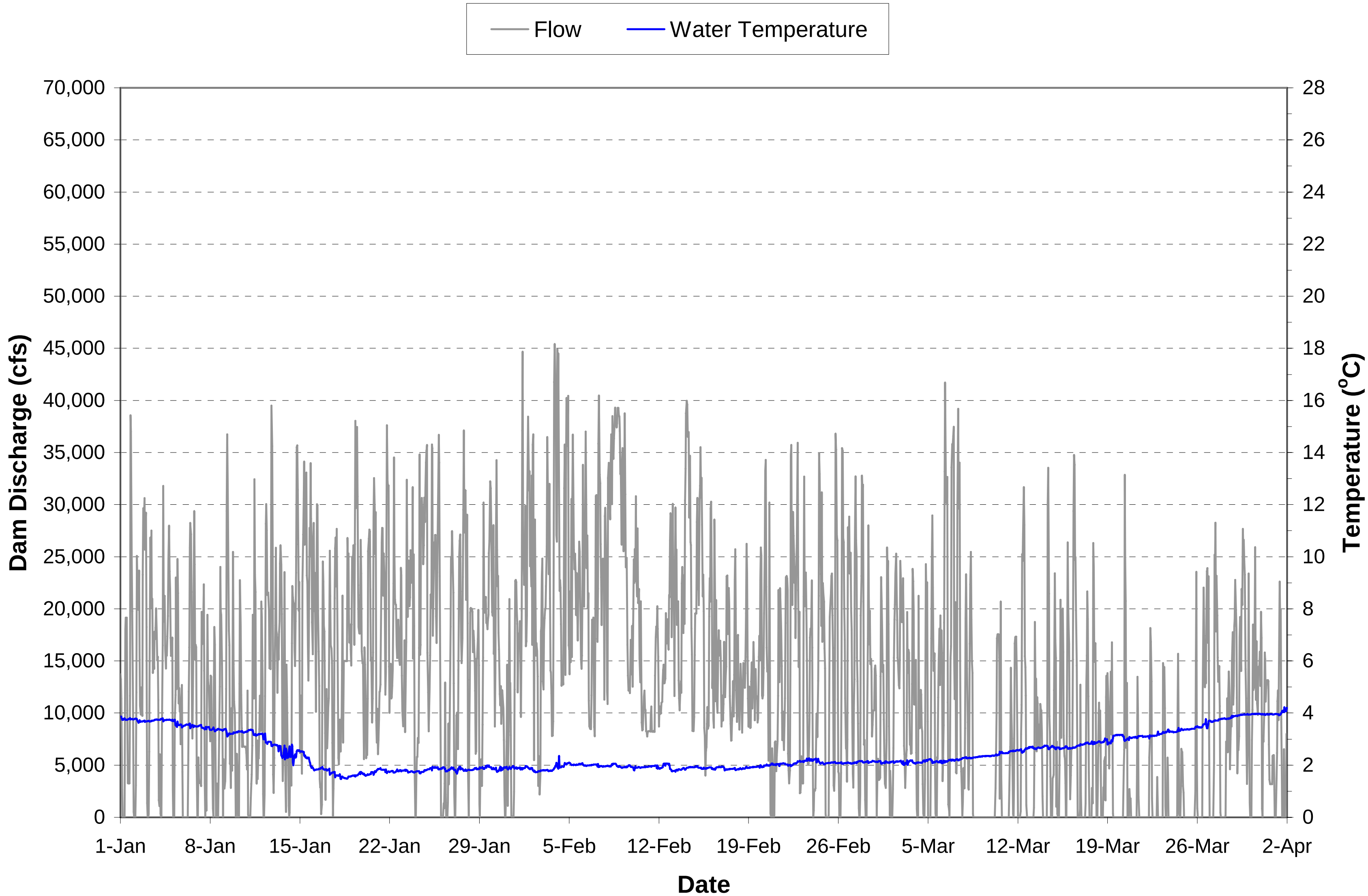

Plate 62. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period January through March 2007.

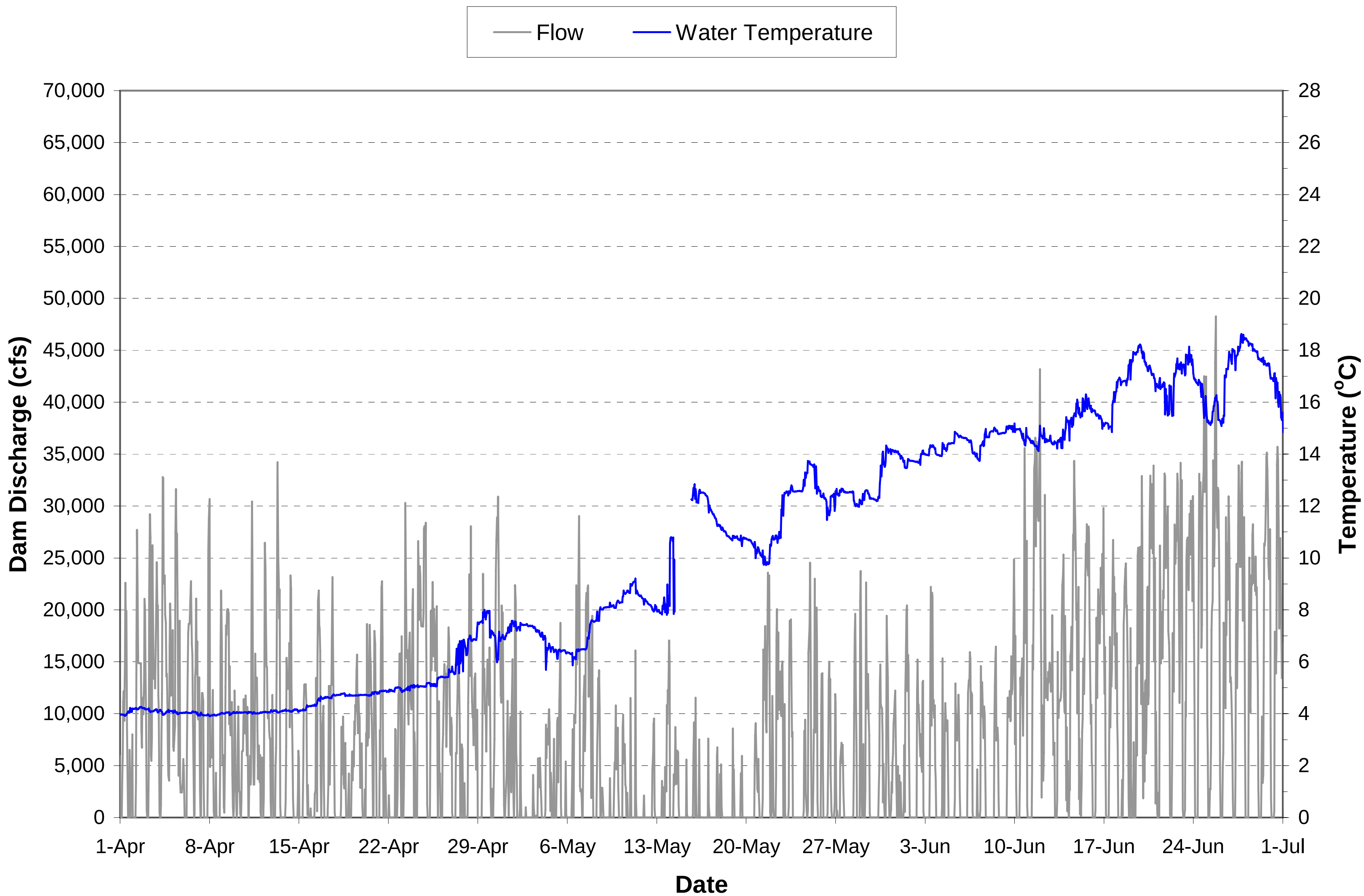

Plate 63. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period April through June 2007. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

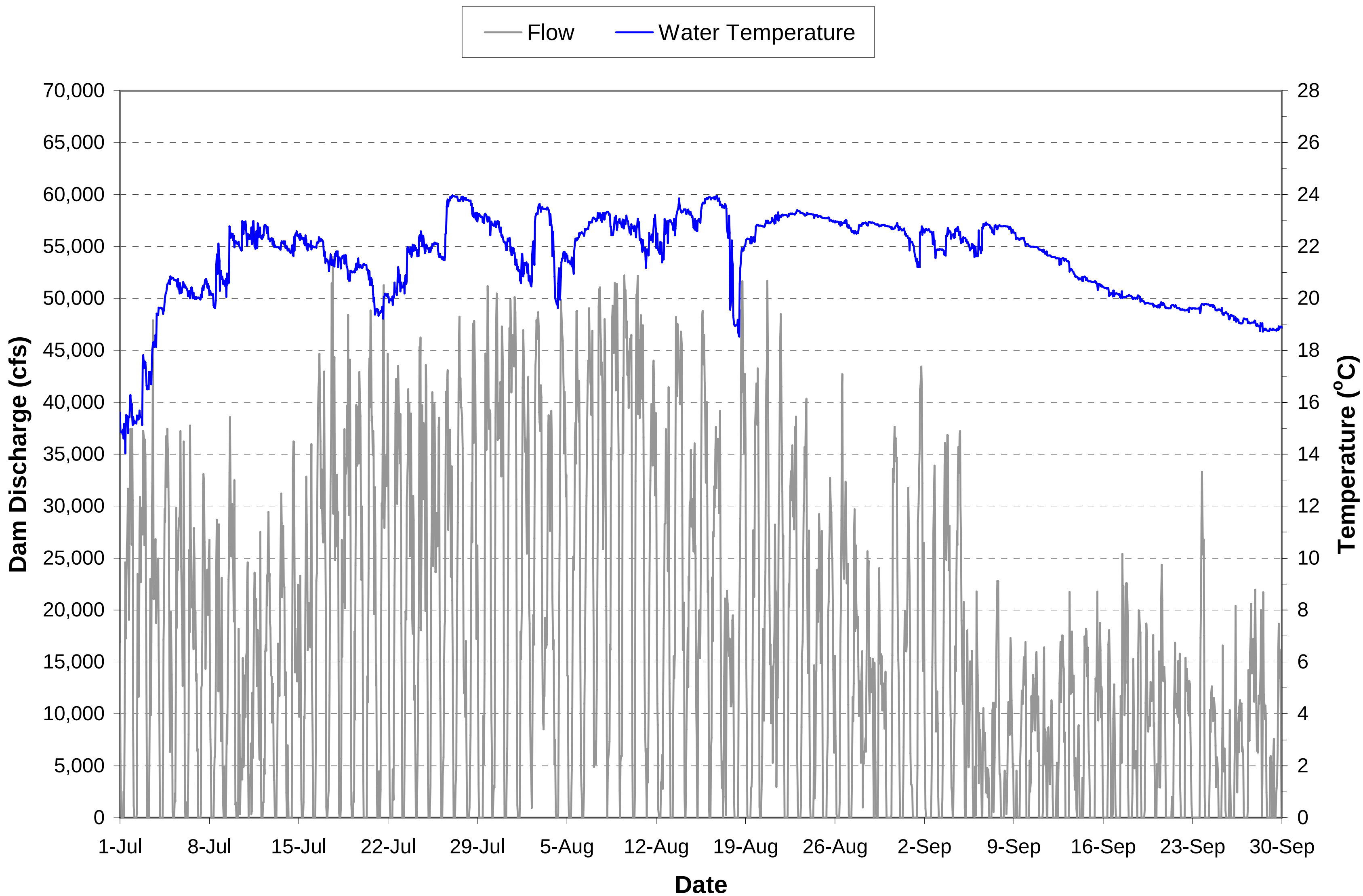

Plate 64. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period July through September 2007.

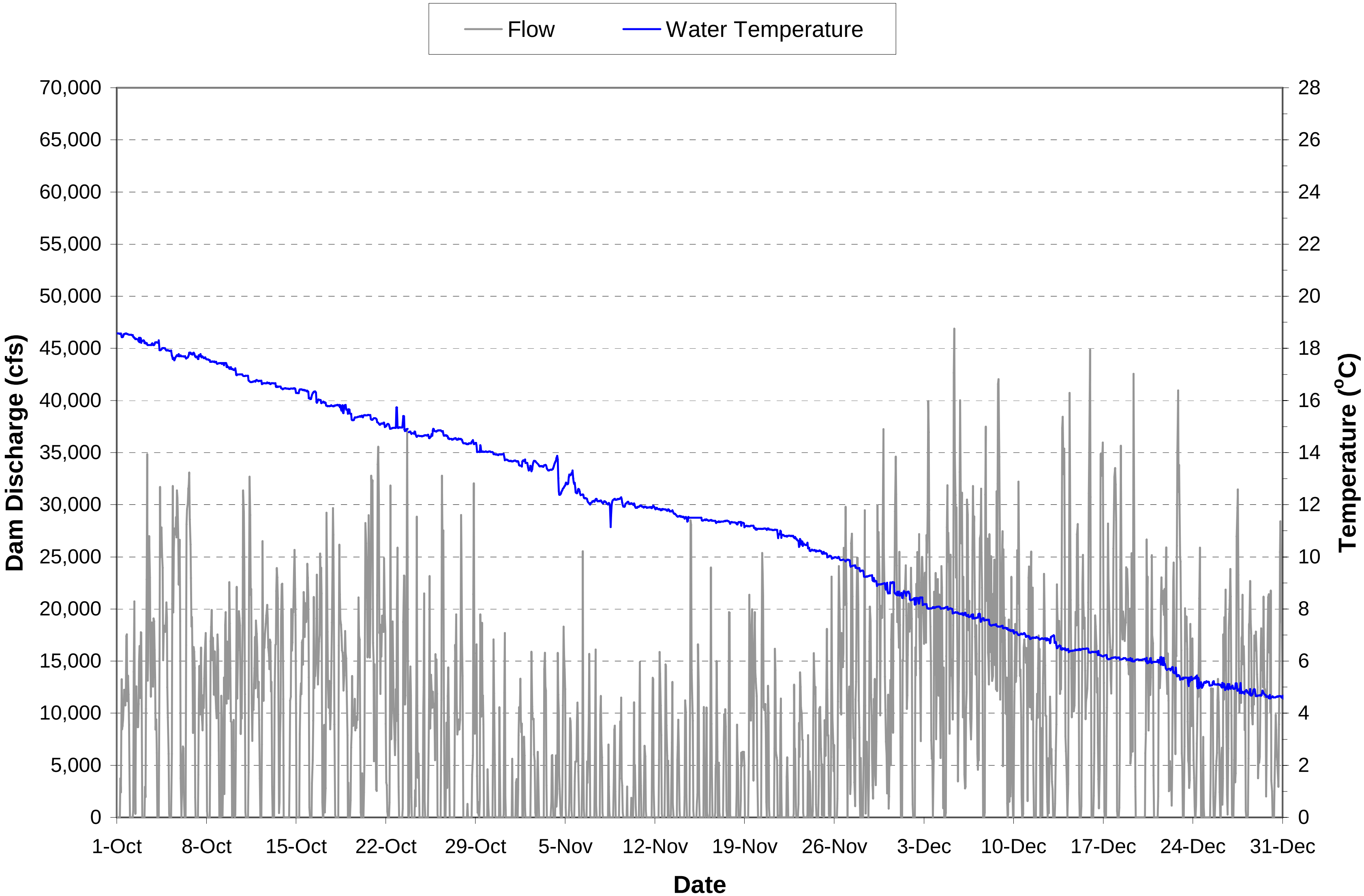

Plate 65. Hourly discharge and water temperature monitored in the "raw water supply line" at the Oahe powerhouse during the period October through December 2007. (Note: Gaps in temperature plot are periods when the monitoring equipment was not operational.)

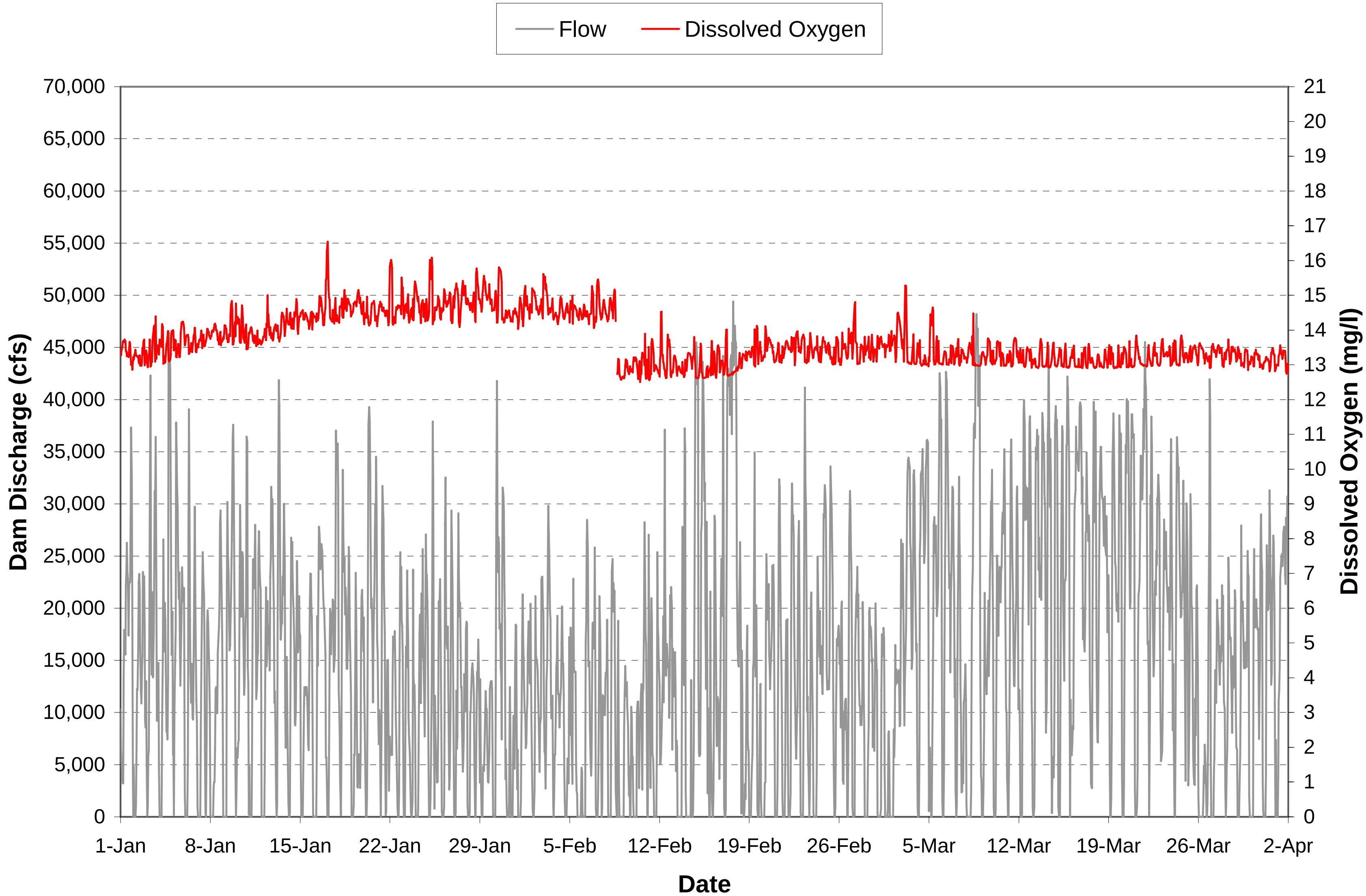

Plate 66. Hourly discharge and dissolved oxygen concentrations monitored in the “raw water supply line” at the Oahe powerhouse during the period January through March 2006.

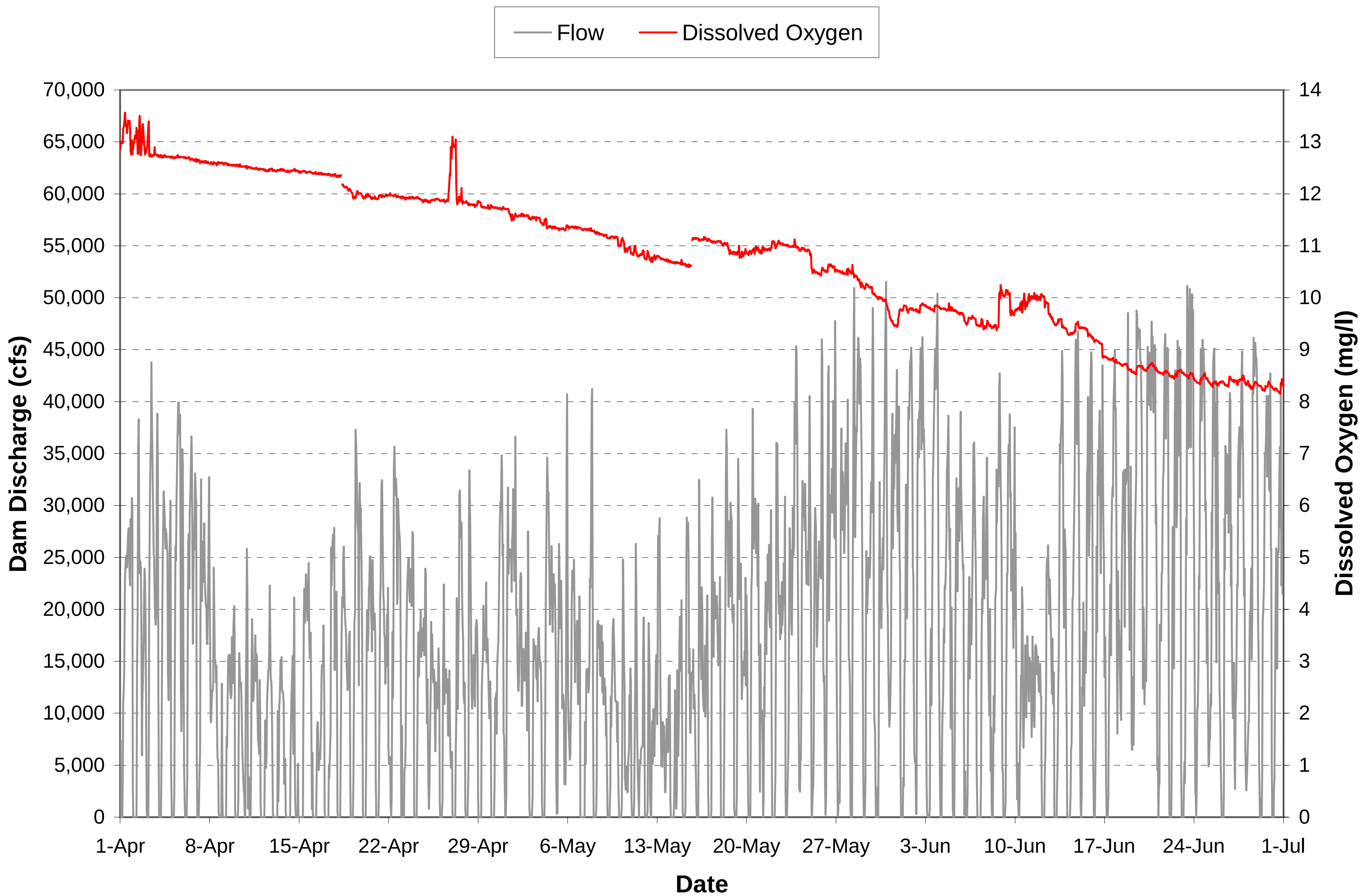

Plate 67. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water supply line" at the Oahe powerhouse during the period April through June 2006. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)

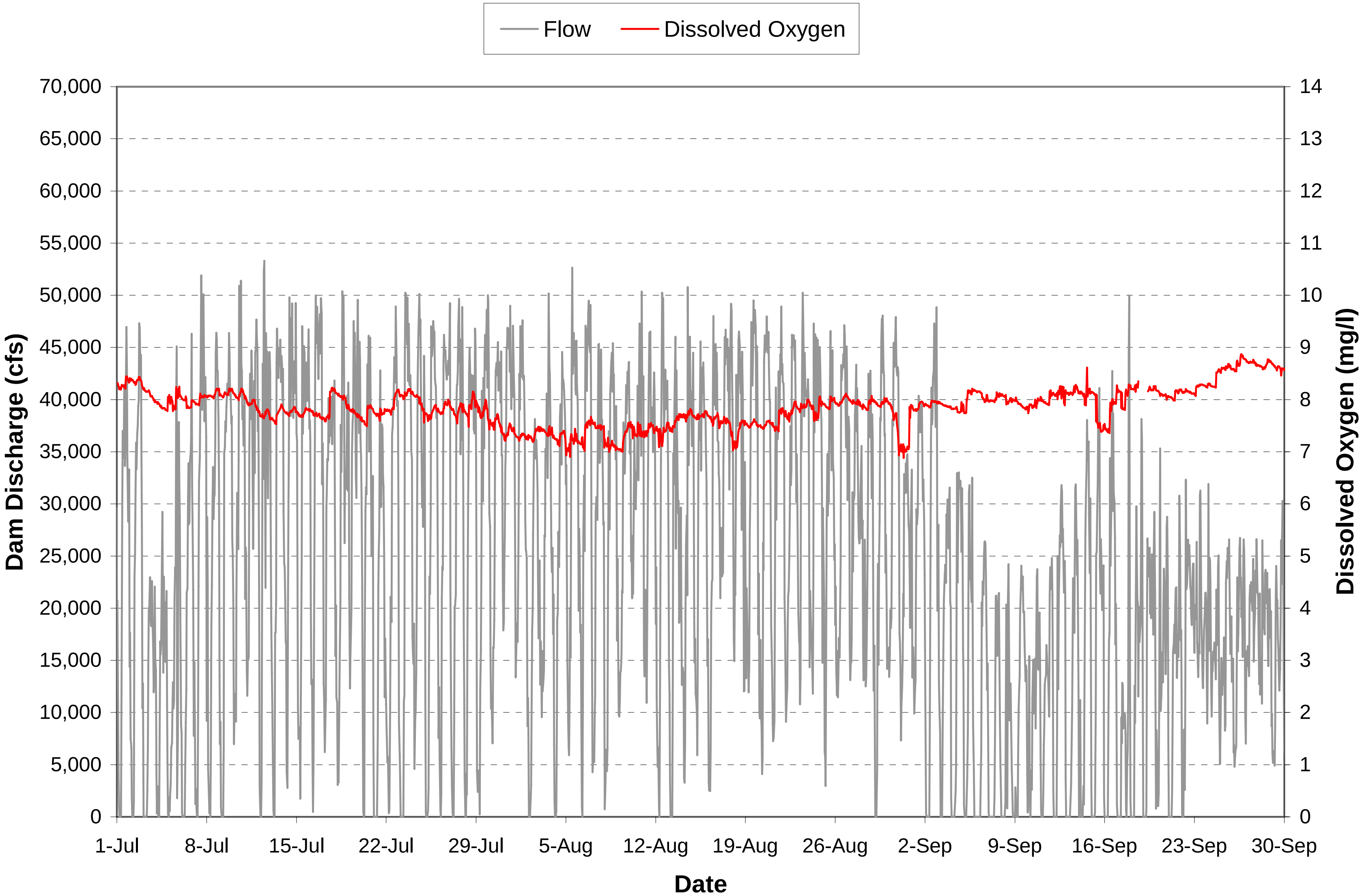

Plate 68. Hourly discharge and dissolved oxygen concentrations monitored in the “raw water supply line” at the Oahe powerhouse during the period July through September 2006. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)

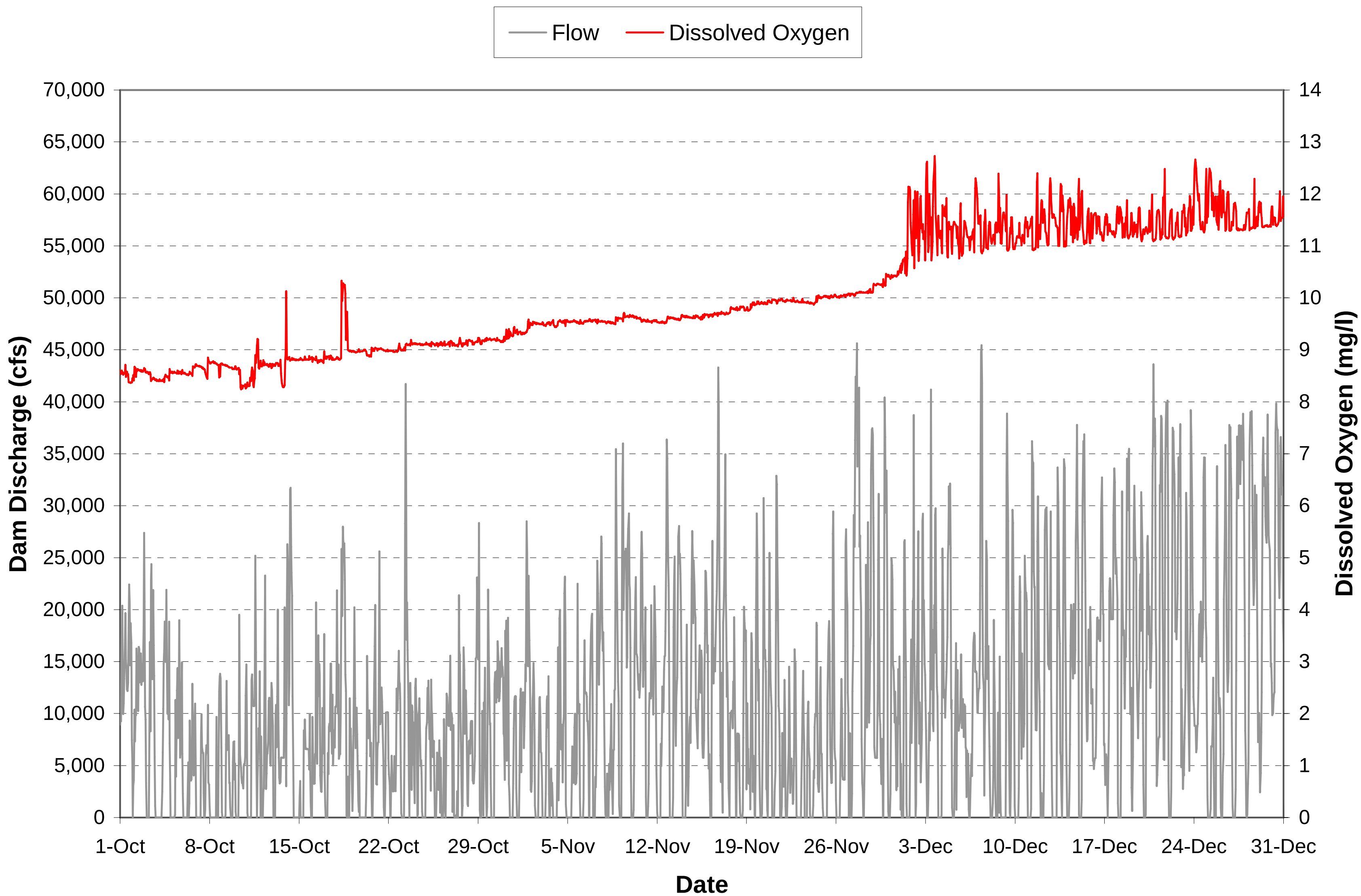

Plate 69. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water supply line" at the Oahe powerhouse during the period October through December 2006.

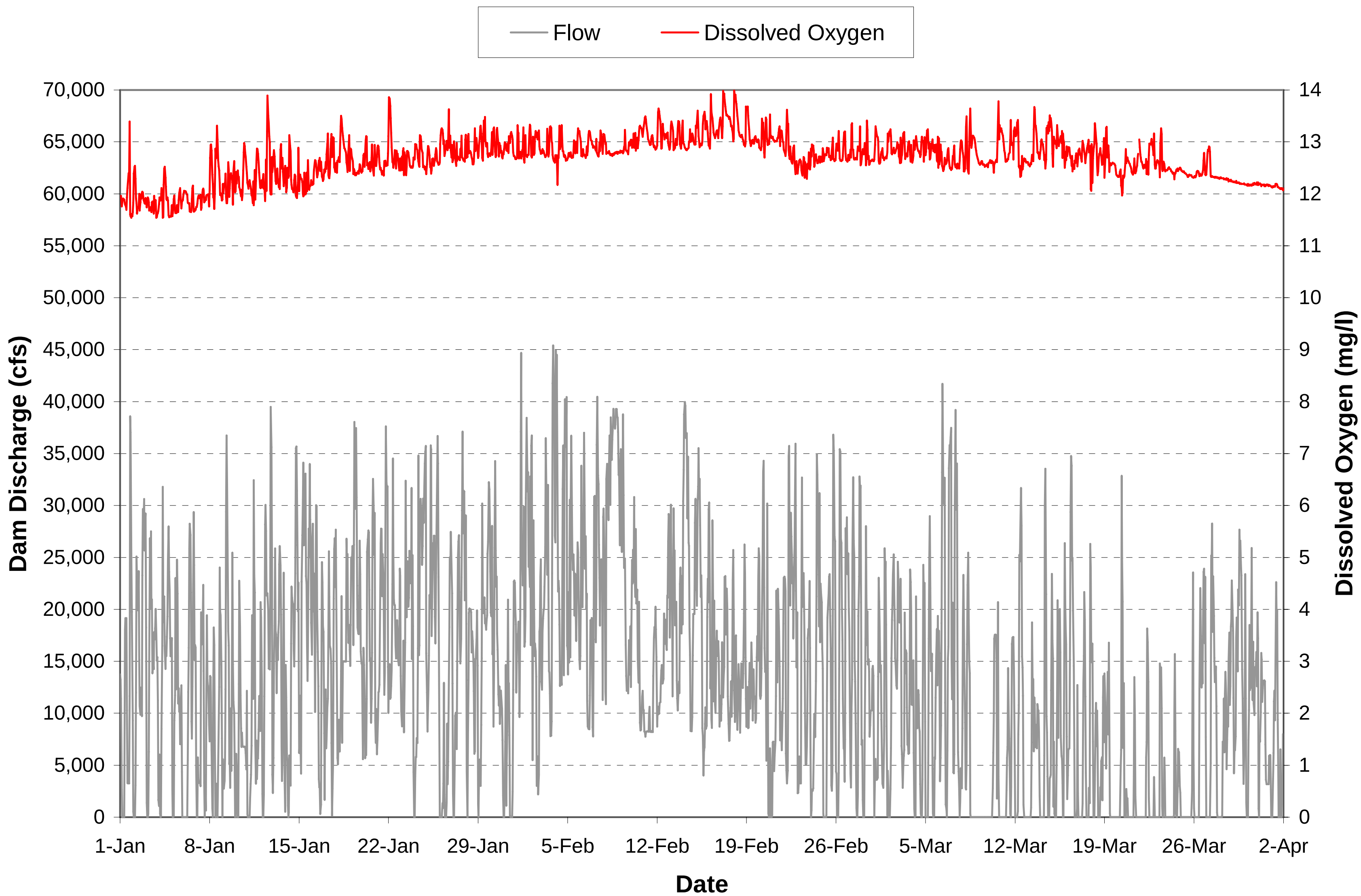

Plate 70. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water supply line" at the Oahe powerhouse during the period January through March 2007. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)

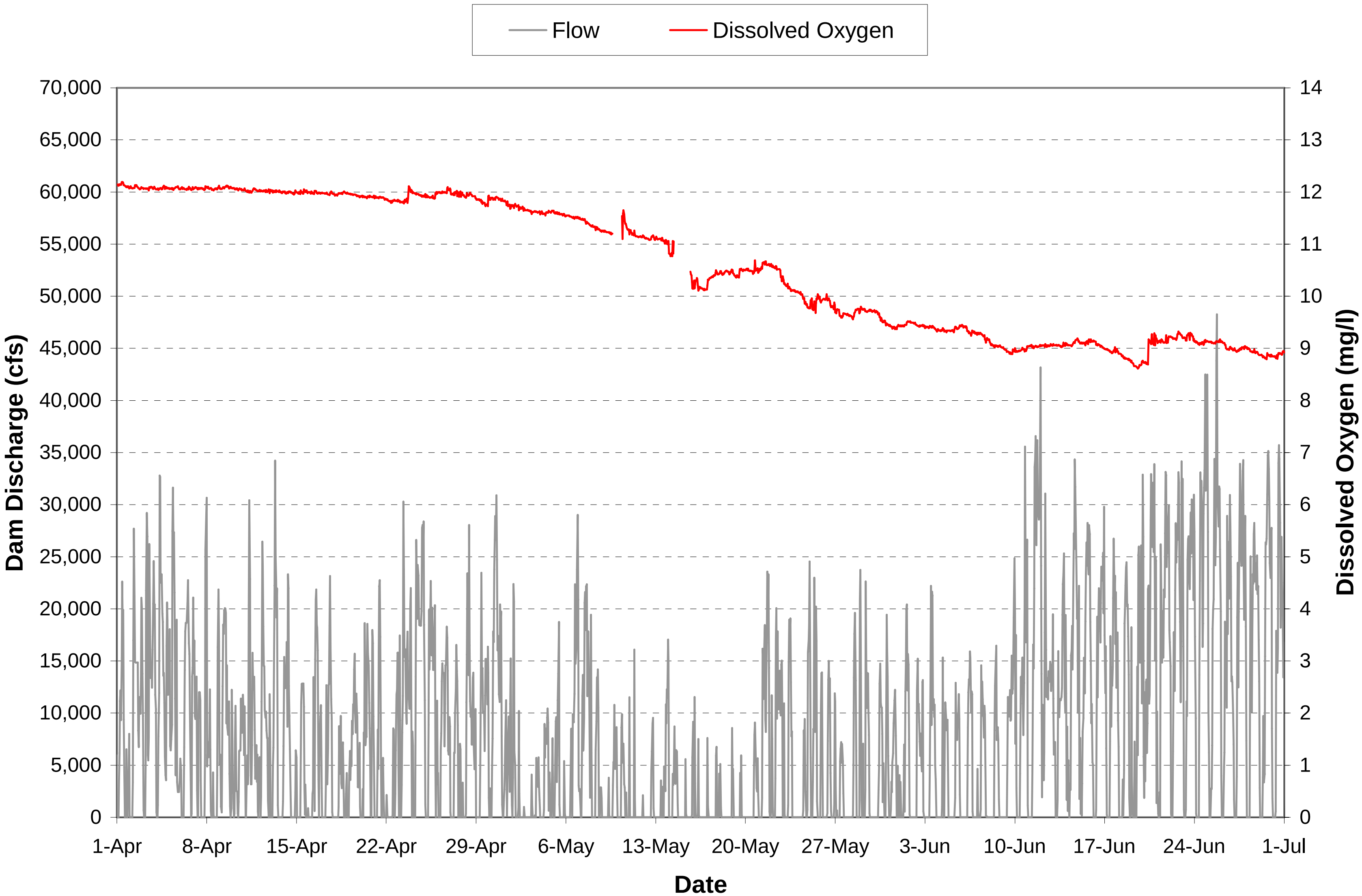

Plate 71. Hourly discharge and dissolved oxygen concentrations monitored in the “raw water supply line” at the Oahe powerhouse during the period April through June 2007. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)

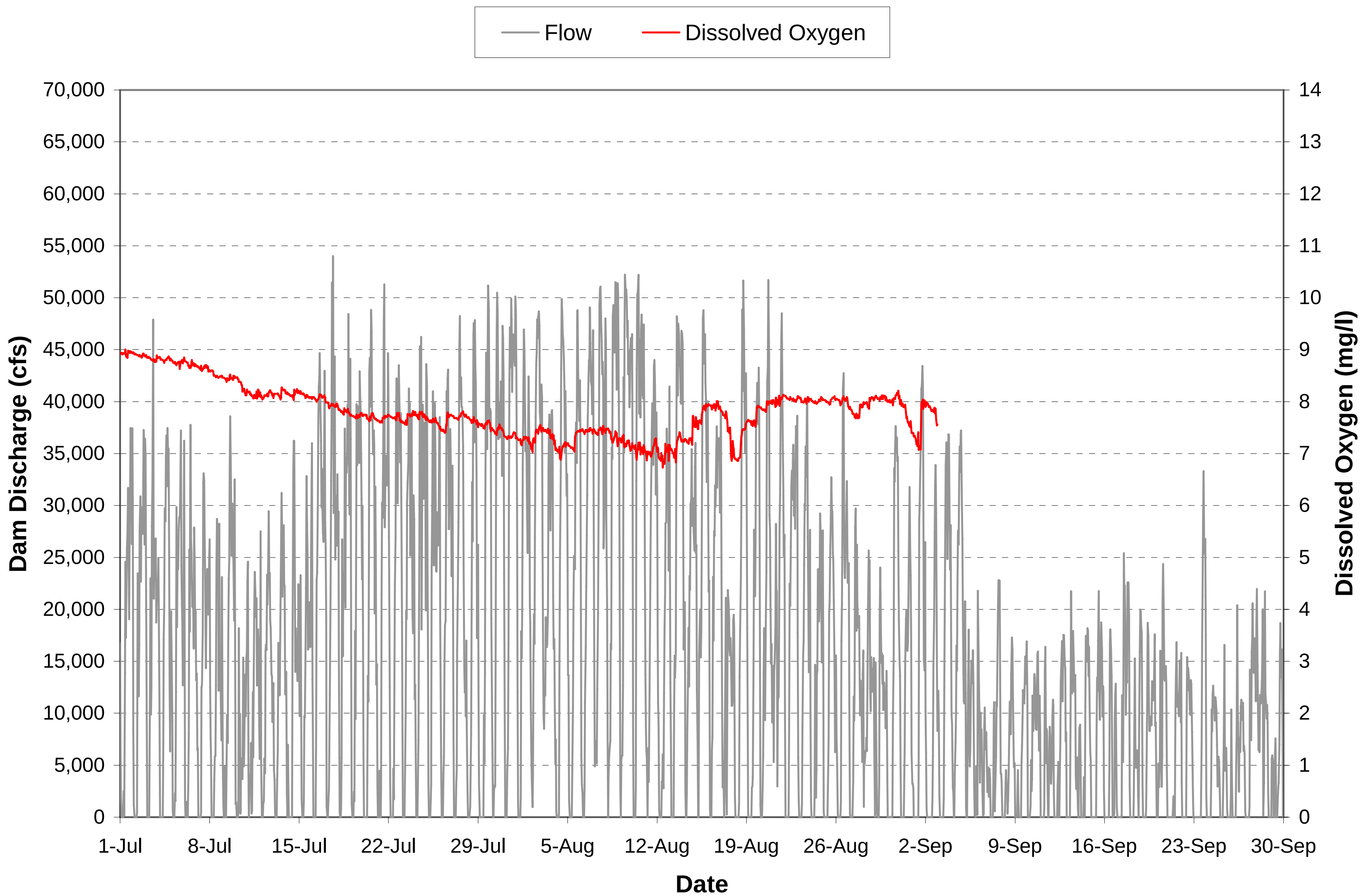

Plate 72. Hourly discharge and dissolved oxygen concentrations monitored in the “raw water supply line” at the Oahe powerhouse during the period July through September 2007.

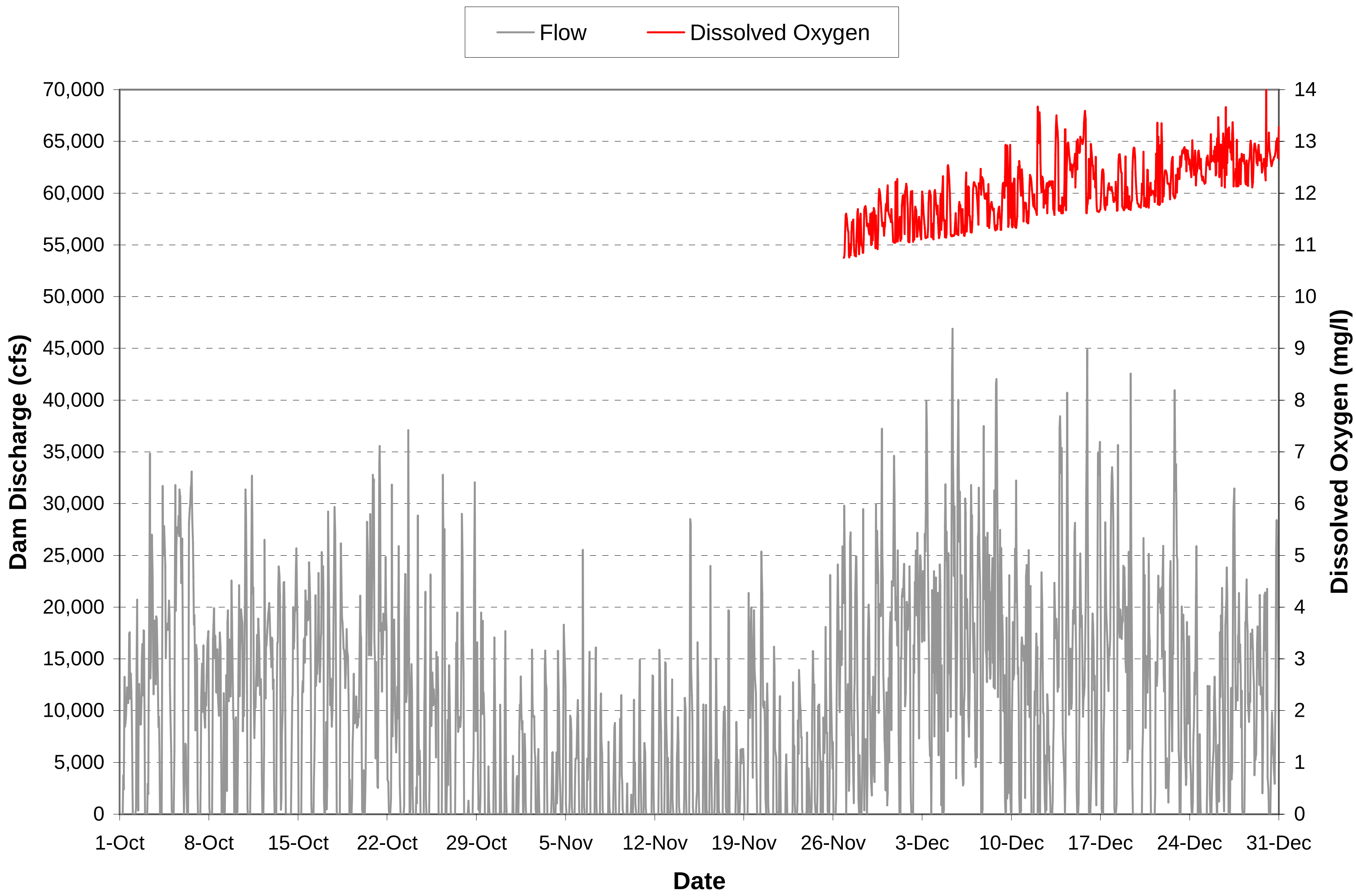

Plate 73. Hourly discharge and dissolved oxygen concentrations monitored in the "raw water supply line" at the Oahe powerhouse during the period October through December 2007. (Note: Gaps in dissolved oxygen plot are periods when the monitoring equipment was not operational.)